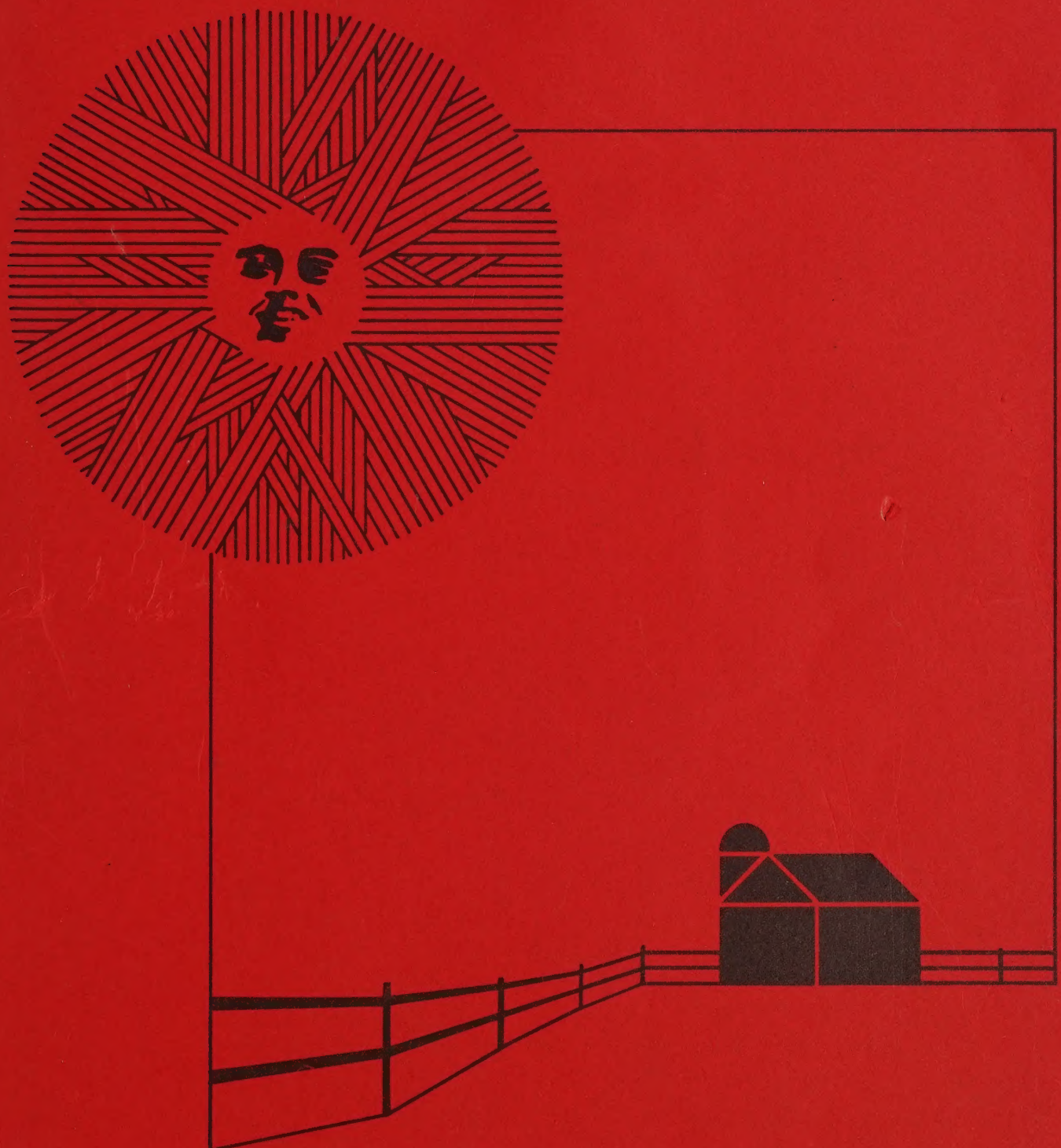
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On-Farm Demonstration of Solar Heating of Livestock Shelters



United States Department of Agriculture

PREPARED BY
Extension Service

PREPARED FOR
United States Department of Energy

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Prepared by
U.S. Department of Agriculture
Extension Service

Prepared for
U.S. Department of Energy
Division of Solar Thermal Energy Systems
Interagency Agreement No. DE-AI01-78CS35149

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SUMMARY

The Department of Energy concluded from the results of the research conducted in the agricultural area with pass-through funds to the Department of Agriculture, that there should be on-farm demonstrations of solar heating of livestock shelters. As a result, nine states were eventually selected to conduct these on-farm demonstrations. There was a total of 80 on-farm demonstrations.

The objectives were (1) to determine the technical and economic feasibility of using solar energy technology for heating systems to provide significant amounts of the heating requirements for on-the-farm livestock shelters, (2) to test, to the maximum extent possible, solar technology developed under the DOE/USDA SEA Federal Research Program operating under farm conditions, (3) to incorporate and utilize energy conservation techniques well known to the industry, (4) to minimize the interruption or interference in the normal operations of the livestock facilities, and (5) to identify incentives and opportunities for widespread farm application of solar energy technology where appropriate.

The program has been worthwhile and appropriate for gathering information on the application of solar energy technology for heating livestock shelters. This has been done with a limited expenditure of public funds.

Through the many workshops, seminars, tours, and other educational meetings, numerous people have gained some degree of knowledge on the application of solar energy to heating livestock shelters.

A copy of each state's report is included in Appendix B.

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FINAL REPORT
ON-FARM DEMONSTRATION OF SOLAR HEATING
OF
LIVESTOCK SHELTERS

INTRODUCTION

By 1978, the research conducted with Department of Energy (DOE) pass-through funds to the Department of Agriculture (USDA) indicated that a substantial amount of fossil fuel energy could be replaced in the heating of farm structures by the applications of solar energy. At that time, DOE became interested in funding on-farm demonstrations of the use of solar energy to heat livestock shelters. An interagency Agreement No. E17-78-I-01-5149 (later changed to DE AI01-78CS35149) was signed by DOE and USDA-ES whereby DOE would pass funds to USDA-ES in the amount of 1.2 million dollars to conduct on-farm demonstrations in the area of solar heating of livestock shelters.

Subsequently, nine states were selected to conduct demonstrations: Illinois, Iowa, Kansas, Minnesota, Missouri, Nebraska, Ohio, Vermont, and Virginia. The nine states were selected through a competitive process. All states were invited to submit preproposals outlining what they would do and how they would proceed. Twenty-one preproposals were received and evaluated by a panel of engineers, architects, and economists. Fifteen states were invited to submit complete proposals for funding. Nine states elected to submit complete proposals and all proposals were accepted with one modification to stay within the allotted funds from DOE.

USDA-ES signed Cooperative Agreements with the nine states and the projects were underway.

OBJECTIVES

The objectives of the program were (1) to demonstrate the technical and economic feasibility of using solar energy technology for heating systems to provide significant amounts of the heating requirements for on-the-farm livestock shelters, (2) to test to the maximum extent possible solar energy technology developed under the DOE/USDA-SEA Federal Research Program under operating farm conditions, (3) to incorporate and utilize energy conservation techniques well known to the industry, (4) to minimize the interruption or interference in normal operations of the livestock facilities, and (5) to identify incentives and opportunities for widespead farm application of solar energy technology where appropriate.

PROCEDURE

The Cooperative Extension Service in each state was invited to submit preproposals outlining what they would do and how they would proceed. Twenty-one preproposals were received and evaluated by a panel of engineers, architects, and economists. Those people on the evaluation panel were William T. Cox, Extension Service, USDA; Robert G. Yeck, Agricultural Research Service, USDA; Richard Slatter, Farmers Home Administration, USDA; Donald VanDyne, Economic Research Service, USDA; and Paul Barns, Department of Energy.

The following criteria were used in evaluating both the preproposals and the proposals: quality of technical approach, potential cost effectiveness, scope of potential applications, plans for public exposure, adequacy of project management plans, and prior experience in solar energy application.

Fifteen states were invited to submit complete proposals for funding. Nine of the fifteen states elected to submit complete proposals. The proposals were evaluated by the same committee that evaluated the preproposals. All 9 of the proposals were accepted and Cooperative Agreements were signed with the 9 states. Figure 1 is a map showing the locations of the selected states. A 3-year budget was submitted as a part of each proposal. A copy of the suggested format for the budget is included in Appendix A.

There is a total of 80 on-farm projects in the 9 states. A classification of the projects is given in Table 1. There is overlapping of the classifications in most areas; thus, the totals are usually greater than the number of projects. The original plan specified that there would be approximately 10 projects in each state. With the low farm prices and the high interest rate on borrowed money, several of the original participants discontinued their involvement. In some cases, the state project manager could find a substitute participant but not in all cases; thus, the final number was 80 projects instead of the original 90 projects.

The project manager in cooperation with the farmer participant completed a design for each project and submitted it to ES-USDA for approval. ES-USDA established an advisory committee of knowledgeable people in the use of solar energy in agriculture to review the designs and make comments regarding the merits of

the design. The Advisory Committee consisted of J. P. Mason, Professor, Agricultural Engineer, VPI & SU; Charles K. Spillman, Professor, Agricultural Engineer, Kansas State University; Kenneth E. Felton, Professor, Agricultural Engineer, University of Maryland; and Paul Barns, Department of Energy. Many of the designs were reviewed at meetings at which the project managers could explain their project designs to the Advisory Committee and answer any questions. Other designs were reviewed by mail. The review meetings proved to be the more satisfactory method.

Following the reviews, the ES-USDA representatives reviewed the results and wrote a letter of approval or disapproval to the project manager. Comments of the review committee members were included in the letters to the project managers. The project managers had an opportunity to revise and resubmit the design for further consideration.

A part of the funding for each state project could be used to refund the farmer participant a portion of the expense for the solar addition to the project. Except in unusual circumstances, this could not exceed 50 percent of the total cost for the solar addition.

An agreement was drawn up between the Cooperative Extension Service of the University and the farmer participant outlining the responsibilities of the parties involved. A sample agreement is included in Appendix A. Necessary instrumentation was installed so that data could be collected to determine the actual solar energy collected by the system, the efficiency of the system, and the economic feasibility of the system. There was no set equipment or procedure established for data collection and analysis. It was the prerogative of the project manager to determine the instrumentation needed for his projects.

A review of the 80 projects (See Table 1) showed that there were 65 air collectors and 17 water collectors - a total of 2 more than the number of projects. Thus, two projects used both air and water collectors. There were 62 swine structures heated, 18 dairy, 3 poultry, 1 veal, 1 general, and 4 crop drying. Another classification of the projects showed 76 incorporating space heating, 9 domestic hot water heating, and 4 crop drying. This indicates that 9 projects were multi-purpose projects. There were 1 portable collector and 79 stationary collectors. Energy storage was included in 60 of the projects.

FIGURE 1. THE NINE STATES THAT ARE INCLUDED IN THE ON-FARM DEMONSTRATION OF SOLAR HEATING OF LIVESTOCK SHELTERS



TABLE 1: Summary of the On-Farm Demonstrations

Solar Heating of Livestock Shelter Projects

Cooperators 80

Solar Collectors

Transfer Media: Air 65

Water 17

Type of Structure: Portable 1

Stationary 79

1. Modified Trombe Wall 27
2. Roof 13
3. Attic 10
4. Free Standing 5
5. Other 29

Storage: Yes 60 No 20

Type: 1. Water 18

2. Rock 9
3. Modified Trombe Wall 27
4. Other 9

Use: Space Heating 76 Crop Drying 4 DHW 9

1. Swine 62
2. Dairy 10
3. Poultry 3
4. Other 1

1. Dairy 8
2. Veal 1

ECONOMIC EVALUATION

Illinois

A simple collector for preheating ventilation air should cost between $1.00 and $3.00 per square foot. Fossil fuel replaced with a solar collector on a 4/12 slope having an efficiency of 15% is about $0.25 per square foot per heating season if L.P. gas at $0.60 per gallon is the fossil fuel. Based on these figures, simple payback for the collector would be 4 to 12 years.

Iowa

The cost of collector versus the savings per year varied from 1.80 to 13.11. After eliminating the highest and lowest ratio, the average is 6.14. Recovery of investment is therefore in 6 plus years.

Kansas

In the Kansas economic analysis, a 10-year payback, tax credits, and operating and maintenance costs were considered (life cycle economic analysis). However, based on cost versus return only, the average payback after dropping the highest and lowest payback periods was 11 years.

Missouri

For those projects where simple payback was figured, the average was 8 years. However, three systems on dairy milking structures were very expensive and a payback was not possible.

Nebraska

For 6 of the 8 projects in Nebraska, the average payback was 12.2 years.

Ohio

Overall solar systems with a simple design built as part of a new structure offer the greatest potential for Ohio farms.

Vermont

The payback was not favorable on any of the projects. Simple payback varied from 11 to 43 years.

Virginia

The economics of solar heating for livestock shelters are not attractive at the current time. Payback periods of 10 to 20 years can be expected unless extreme care is used to control the initial cost of the installation.

EDUCATIONAL ACTIVITIES

Illinois

Nine publications and papers were written and appeared as articles in popular magazines or Extension publications or were presented as technical papers. An 18-minute videotape was made and distributed for various uses. Three construction plans (Lean-To Solar Collector With Rock Storage, a 600-Sow Solar Heated Swine Production Unit, and a 300-Sow Solar Heated Swine Production Unit) were designed and drawn for distribution to the public. In 1981, 14 solar workshops were held for producers with an attendance of 715. There were 7 solar tours that had 500 in attendance. In 1982, 8 producer solar workshops, 4 farm builders solar workshops, 33 swine seminars, and Illinois' Farm Structures Day were held with a total attendance of 1,670.

Iowa

Iowa developed a 26-minute, 77-slide tape set entitled, "Solar Heat for Swine Facilities: Iowa's Demonstration Project." The set presents basic solar information, describes the project, presents information on each cooperator's system and gives recommendations. One set will be available from Media Resources on the Iowa State University Campus, two from Agricultural Engineering Extension, and one from each of the 12 Extension area offices.

A paper was prepared and presented at the Iowa Solar Operational Results Conference. Its title was "Solar Heating of Livestock Facilities: Iowa's Demonstration Project."

A field day at the farm of one of the cooperators was held in 1980 at which the cooperator, the local county Extension Director, and two agricultural engineers gave presentations and were available to answer questions and demonstrate the data acquisition equipment. Problems with seeing slides and video displays and concern about spreading swine disease led to a decision to hold no more field days.

Two series of Cooperative Extension bulletins were developed on the project and made available through Iowa State University's Publications Distributions.

Iowa (cont'd)

About 115 presentations on solar heat for livestock buildings and the demonstration project have been given or are planned to be given this year.

Two identical displays for use at fairs, meetings, and energy events have been developed.

A microcomputer is being used to evaluate the economic worth of solar preheating ventilating air for swine buildings.

Kansas

An outdoor display was developed, which included solar energy educational methods for use at the Kansas State Fair. It included a model of the Kansas State wall (a modified Trombe Wall) as well as information regarding the on-farm demonstrations of solar heating of livestock structures.

Twenty-five county and area meetings were utilized to explain the solar livestock demonstration grant to the general public.

Several television and radio programs to explain the on-farm demonstration programs and to present in-depth interviews were conducted. Also, at least one tour was held at one of the farmer/cooperators to explain the functions of the on-farm demonstration programs.

Seminars, professional engineering meetings and the popular press have been utilized to give additional coverage to the program. One of the cooperators received a national energy conservation award from President Carter in 1980. An update on the project was presented to the Kansas Pork Producers Council Meeting on February 10, 1982.

During the 1981-82 Extension year, meetings were held in 16 counties to inform livestock producers about the solar demonstrations.

Although interest remains high and the cooperators have presented information on their solar installations at livestock meetings, there has not been a great number of new units constructed. This is felt to be due to low farm prices.

Minnesota

Printed results of the demonstrations have been distributed to the county agents. This will be followed with Fact Sheets. An audio-slide set has been prepared and, following updating, will be distributed to the county agents.

Energy meetings have been held at five locations and five more are planned to be held by the end of March 1983.

Many phone calls have been received requesting information on solar energy.

Journal articles in Transactions of ASAE are planned.

Missouri

Seminars were conducted on solar designs and operations at local and state meetings and meetings of farm builders involved in construction of solar units. In-depth training sessons for area Extension staff were conducted.

Design procedures were developed for solar systems used for water heating and ventilation air preheating.

Informational meetings were held for representatives of the Farm Credit Industry and tours were conducted for farmers interested in solar application.

Publications and other mass-media materials were developed as a direct result of the project.

Nebraska

Over 300 copies of the Solar Modified Open Front (MOF) Nurseries (Projects NE1 and NE10) have been distributed, not only in Nebraska but throughout the world. Two 1:20 scale models have been built and used for display at pork producers' meetings, field days and fairs.

Information from this project was used in the design of the solar heated swine facility at the University of Nebraska's Energy Integrated Farm Extension Demonstration Project.

A 4-page informational pamphlet on solar collectors and the Solar MOF Nursery is nearly ready for distribution and 3 slide-tape sets are being planned.

Nebraska (cont'd)

Knowledge gained from the project was included in the in-service training program for county Extension agents on the topic of solar energy for agriculture.

Various installations have been featured in at least 6 states and/or national swine and solar magazines.

At least 7 technical papers have been prepared and presented. Several articles have been prepared that discussed one or more of the demonstration projects.

Ohio

Mass media was eager to cover the events of the solar demonstration project. The media coverage of the 10 solar field days and open houses at the cooperating farms reached thousands of people. The attendance at these field days and open houses was 1,200. Through 75 formal presentations, the project director has reached approximately 4,000 farmers, farm builders, engineers, extension faculty, and students.

A slide set with a 12-minute cassette tape and 3 to 5-minute radio tapes have been used to bring the solar demonstration projects to the attention of the people in Ohio. The project director has discussed the solar projects on 7 live radio interviews and 1 television news program. Ten educational news releases concerning the project have been distributed.

The projects have been featured in several national and state publications. Also, the hog farmer magazine of France, "L'eleveur De Procs" included a 5-page article on the Ohio solar systems and featured one of the buildings on the cover.

Vermont

Eight 17-minute television tapes have been prepared. Estimated viewing audience is 100,000 for each of these. In addition, 4 shorter television tapes for news programs have been prepared. Twenty-one 3-minute radio tapes have been distributed to 27 radio stations.

There has been a large number of press and news releases carried in local, regional and national newspapers and magazines. Some major ones include the Boston Globe, Farm Builders News, and the Northeast Solar Energy Center Update.

Fourteen official visits and open houses with approximately 800 in attendance have been held. Each site has been visited by a group of 10 or more people at least one time.

There have been 10 meetings where solar energy was a part of the program, with approximately 800 in attendance.

There have been 27 informational sheets written, each with a distribution of approximately 3,000 copies. Three papers have been presented at professional meetings.

Three scale models and one informational display have been developed and used at county fairs, energy fairs, libraries, schools, and other locations.

Other activities planned include (1) a 10-12 minute slide/tape cassette audio/visual program for use by Extension agents and others, (2) a 20-25 page Extension Bulletin, and (3) a 20-minute video tape summary of the project and two 15-minute television programs.

Virginia

Fact Sheets describing each system were prepared and distributed. Several news articles have been prepared describing the systems. Also there have been television appearances and radio tapes prepared.

One of the projects was a prominent part of the 1982 Farm Management Tour.

A display of the systems has been prepared to show at energy fairs, Virginia State Fair, utility offices, and other appropriate places.

Plans for the systems have been prepared and distributed upon request. Work on other solar installations has resulted from these projects.

A slide-tape presentation on ways to save energy and money for domestic hot water has been prepared for use in 1983.

GENERAL CONCLUSION

This program has proven to be very worthwhile and appropriate for demonstrating the application of a relatively new technology to an ongoing technology (Solar Energy for Heating Livestock Shelters).

Not only has the gathering of information been successful, it has been done with a limited expenditure of public funds. The educational value of the program is impossible to establish. However, during the progress of the program, many agricultural engineers have gained valuable knowledge regarding solar energy, as well as the problems and solutions involved in applying solar energy to the heating of livestock shelters.

Through the many workshops, seminars, tours, and other educational meetings, an untold number of people has been exposed to the applications of solar energy in heating livestock shelters.

In the farming community, there is a great deal of individual visiting by farmers to facilities in which they are interested. This is very true in the case of solar energy as indicated by farmers who have numerous visitors to their solar energy systems. These meetings and visits will continue as long as the systems are in good operating condition.

SPECIFIC CONCLUSIONS AND RECOMMENDATIONS

1. Careful planning, construction, management, and maintenance can make solar heating of livestock housing a significant economic alternative to conventional housing.

2. Insulate building before spending money on solar energy.

3. Make multiple use of solar systems. This increases the return from the solar investment.

4. Solar systems for preheating ventilation air can be made both simple and efficient.

5. For collectors for heating livestock ventilation air, provide a minimum of 1 square foot of collector area per 1 to 4 CFM of ventilation air.

6. The building should be as airtight as possible.

7. Provide method of by-passing the collector on warm days.

8. Vent, cover, or shade collector in summer to keep cool.

9. Do not use polystyrene insulation in a collector; it melts at high collector temperatures.

10. The design of a solar system for preheating livestock ventilation air is complex enough to require assistance from people familiar with both solar energy systems and animal ventilation systems.

11. Preheating of ventilation air seems to be the most feasible application for solar energy in livestock production.

12. Solar systems should have storage to effectively utilize solar energy in modern livestock structures at night when outside temperatures are at a minimum and direct solar energy is not available.

13. Although the attic or whole roof collector systems are the least expensive, they usually have a low efficiency.

14. Usually a solar system is not an economically feasible alternative for providing hot water for use in a dairy milking center.

15. In the northeastern United States, solar energy appears to have limited use in livestock structures; however, for specialized production such as veal calf and poultry operations, consideration should be given to the use of solar energy.

16. Solar heating systems can be constructed so that they function effectively and reliably on livestock farms.

17. Home built systems tend to be less expensive than commercial units.

18. Heated floor units using water from a solar system are inherently inefficient because the auxiliary heating system maintains the operating fluid at a relatively high temperature (above $110^{O}F$).

19. Solar storage walls (modified-Trombe Wall) can be built at a relatively low additional cost if constructed when the structure is initially built.

APPENDIX A

Suggested Format for Budget

Agreement Form Between State and Cooperator

Form for Cooperative Agreement Between the Cooperative Extension Service and ES-USDA

BUDGET

ITEM	YEAR 1	YEAR 2	YEAR 3	TOTAL
I. ANNUAL COST				
II. SOURCE OF FUNDS				
University				
Farmer Cost Share				
USDA:SEA				
TOTAL				
III. SALARIES				
(A) Professional				
Ex. Assistant				
FTE				
(B) Graduate Student				
Student Labor				
(C) Draftsman (FTE)				
(D) Secretarial (FTE)				
(E) Staff Benefits				
TOTAL				
IV. TRAVEL				
V. EQUIPMENT				
(A) Solar[1]				
Equipment				
(B) Instrumentation[2]				
and Monitoring				
TOTAL				
VI. SUPPLIES				
VII. OTHER				
Telephone and Copy				
Service				
Maintenance-Inst.				
TOTAL				

[1] Title to be vested with cooperating farmers at time of making cost share payment.

[2] Title to be vested with University of at termination of project.

COOPERATIVE AGREEMENT
between
THE COOPERATIVE EXTENSION SERVICE
UNIVERSITY OF
and
EXTENSION SERVICE
UNITED STATES DEPARTMENT OF AGRICULTURE

I. PURPOSE

The purpose of this agreement is to demonstrate the potential of solar energy in providing a significant portion of the heating energy requirements for on-the-farm livestock shelters.

II. SITUATION

Having shown the technical feasibility of providing a significant portion of the annual heating requirements for USDA-ARS experimental livestock shelters and because fuel costs represent a significant amount of the operational costs, the Department of Energy (DOE) has pursued a vigorous program in the application of full scale prototype systems for solar heating of on-farm livestock shelters. Consequently, DOE has made $1.2 million available to USDA - ES for the establishment and demonstration of solar energy heating systems for dairy buildings, poultry brooding buildings, and swine farrowing houses. The selection of projects was based upon preproposals and full proposals submitted by the Cooperative Extension Services interested in the program. Each project is cost-shared and may consist of single or multiple buildings and single or multiple farm locations.

III. AGREEMENT

It is agreed that the Extension Service - USDA and the Cooperative Extension Service, University of will cooperate for their mutual benefit in an effort to demonstrate the potential of solar energy in providing a significant portion of the heating energy requirements for on-the-farm livestock shelters.

IV. RESPONSIBILITY OF THE PARTIES

A. Pursuant to this agreement the Cooperative Extension Service will:

1. Demonstrate that significant amounts of solar heat can be added to the ventilating air in livestock shelters by incorporating solar energy collectors into the shelters.

2. Evaluate the suitability of various building materials for use in constructing solar collectors in the roof and/or walls of livestock shelters.

3. Determine the approximate savings from the solar heat obtained from livestock shelter solar collectors and the added construction costs and/or extra operating costs.

4. Demonstrate that livestock shelter solar collectors can be used for: (a) heating ventilation air, (b) heating water, and (c) crop drying.

5. Improving the design and develop better plans for the construction of solar systems incorporated into livestock shelters, at the same time utilizing accepted energy conservation techniques.

6. Make available to the Extension Service - USDA all material developed as a part of this project.

7. Furnish progress reports as requested by the Extension Service Liaison Officer.

8. Impose no negotiated overhead or indirect cost rate on funds received to finance this project. Any and all indirect costs will be considered a part of the contribution of the Cooperative Extension Service, University of .

9. Provide Extension Service - USDA quarterly a statement of costs incurred by expenditure classification. The first report covers costs incurred through September 30, 1979, and is due in Extension Service - USDA 15 days after the end of the quarter.

B. Pursuant to this agreement the Extension Service - USDA will:

1. Authorize funds in the amount of in an amendment to the letter of credit. Total cost to Extension Service - USDA under this agreement will not exceed . All funds are subject to the provisions of Section C-3.

2. Provide technical assistance and guidance as needed.

C. Pursuant to this agreement it is mutually agreed that:

1. This agreement shall become effective on the date of the last affixed signature and shall remain in effect until September 30, 1979, unless extended by mutual consent.

2. This agreement may be terminated at any time by either party upon receipt of written notice 30 days in advance of the intended date of termination.

3. Should there be any unobligated funds remaining, at the conclusion of the project, such funds shall be refunded to the Extension Service - USDA and any undrawn authorization under the letter of credit revoked.

4. Provisions of the approved proposal on which this agreement is based that may not be explicitly stated herein, are considered an integral part of this agreement.

5. The cooperation of the Extension Service - USDA, Department of Energy and the Cooperative Extension Service, University of will be acknowledged on any material published as a result of work carried out under the terms of this agreement.

6. Attached hereto and made a part of this agreement are the provisions of Executive Order No. 11246, dated September 24, 1965, Sec. 202, para. (1) through (7). As appearing throughout these paragraphs, the word "contract" shall be construed to mean "agreement" and the word "contractor" shall be construed to mean Cooperative Extension Service.

7. No member of or delegate to Congress shall be admitted to any share or part of this agreement, or to any benefit that may arise therefrom; but this provision shall not be construed to extend to this agreement if made with a corporation for its general benefit.

IN WITNESS WHEREOF, the parties whose signature appear below admit to having authority to enter into such agreements and agree that this agreement shall become effective on the date of the last affixed signature.

Administrator, Extension Service - USDA	Date
Director, Cooperative Extension Service University of	Date

AGREEMENT

THIS AGREEMENT, by and between UNIVERSITY OF a public corporation of the State of on behalf of the Cooperative Extension Service of the University of (hereafter "University Extension") and of (hereafter "Farm Participant").

WITNESSETH:

WHEREAS, University Extension has sought funds from the U.S. Department of Agriculture to study and

WHEREAS, Farm Participant is desirous of participating in this study of solar heating on his/their farm located at ; and

WHEREAS, it is necessary that University Extension enter into agreements with prospective participants in advance of the award of said grant by the U.S. Department of Agriculture;

NOW, THEREFORE, in consideration of the above and foregoing and the terms, conditions and mutual promises set forth hereafter, the parties mutually agree as follows:

1. That the Farm Participant will allow and cooperate in the construction of a Solar Heating Device or System (hereafter "Solar System") on Farm Participant's located on the above-referenced farm and shall secure and enter into any and all contracts necessary for such construction.

2. That the Farm Participant will construct and manage the Solar System in accordance with design specifications provided by University Extension.

3. That the Farm Participant will assist University Extension personnel in the collection of data regarding the Solar System as requested by University Extension personnel.

4. That Farm Participant will consult with University Extension personnel whenever necessary to maintain proper operation of the Solar System.

5. That Farm Participant will cooperate with and allow the preparation of publicity about the Solar System and the conducting of tours by various groups to study the Solar System operation. All public access to and/or tours of the Solar System shall be done in cooperation with the Farm Participant and shall be done at times and in a manner so as to minimize

the potential of disease transmission and disruption of Farm Participant's operations; provided, however, that University Extension shall assume no responsibility whatsoever for any damages arising from such a tour or tours.

6. That Farm Participant will allow University Extension to make whatever studies, tests and/or reports necessary to fulfill its obligations under the grant and Farm Participant will cooperate as necessary.

7. That Farm Participant shall keep accurate and complete records of all construction costs to serve as a basis for the cost-share allocation from University Extension.

8. That University Extension shall provide the following services to Farm Participants:

a. Provide Farm Participant with solar design criteria and specifications for the Solar System to be constructed by Farm Participant, provided, however, that Farm Participant shall have final approval of the design to be used;

b. Consult with Farm Participant during construction as necessary with regard to construction;

c. Arrange for the installation of necessary recording equipment for an evaluation of the Solar System;

d. Collect and evaluate data from the Solar System;

e. Arrange for and conduct tours or demonstrations of the Solar System in such a manner as to not interfere with good management practices of Farm Participant's Farm;

f. Prepare informational summaries and handouts describing the Solar System and its effectiveness;

g. Provide consultation as needed for day to day operations of the Solar System after completion and until termination of this agreement, provided, however, that University Extension shall not assume any responsibility for repairs required by the Solar System after its construction.

9. University Extension will pay one-half the cost of the Solar System to the Farm Participant; provided, however, that University Extension will only assist with construction of the Solar System and any costs relating to new buildings and/or

facilities are the sole responsibility of the Farm Participant. Said payment by University Extension shall be payable upon completion of operational testing on the Solar System and upon submission by Farm Participant of accurate and complete records of construction costs. This payment is the only financial payment assumed by University Extension.

10. This agreement shall become affective as of the award of funds to University Extension by the U.S. Department of Agriculture and shall terminate on or after the Solar System has been in operation for two full years, whichever occurs later; PROVIDED, HOWEVER, THAT THIS AGREEMENT IS SPECIFICALLY CONTINGENT ON GRANT FUNDS AND SHOULD THERE BE NO AWARD OF FUNDS TO UNIVERSITY EXTENSION BY THE U.S. DEPARTMENT OF AGRICULTURE UNDER THE SOLAR SYSTEM STUDY GRANT, THIS AGREEMENT SHALL BE VOID AND IMMEDIATELY OF NO EFFECT.

11. Farm Participant shall not proceed with any actual construction and/or expenditure of funds until approved by personnel of University Extension.

12. Any and all ownership interests of University Extension in the Solar System as completed and/or materials used in the construction thereof shall be transferred to Farm Participant at such time as the cost-share payment provided for in paragraph 9 above is made.

13. Farm Participant and University Extension shall not be considered joint venturers and/or partners in the construction of the Solar System and Farm Participant shall assume responsibility for any and all claims or liabilities which result from actual construction of the Solar System.

14. This agreement may be cancelled by either party, without liability, by providing thirty (30) days advance written notice to the other party; provided, however, that Farm Participant may not cancel the agreement without the mutual agreement of University Extension after the cost-sharing payment has been made by University Extension.

15. Should Farm Participant terminate this agreement prior to the cost-sharing payment by University Extension, University Extension shall assume no responsibility for construction costs incurred prior to termination; for removal of the solar equipment installed; and/or for restoration of the premises to their former condition.

16. University Extension shall exercise due care in developing the design and specifications for this project and

shall secure peer review of the final design submitted to Farm Participant; provided, however, that University Extension makes or implies no guarantee of performance by the Solar System and NO WARRANTIES OF ANY SORT ARE MADE BY UNIVERSITY EXTENSION.

17. Farm Participant shall bear the risk of loss for destruction or damage to the Solar System during construction and upon its completion and shall be required to maintain adequate insurance to protect its interests therein.

18. This agreement sets forth the entire understanding of the parties and supersedes any and all prior agreements, arrangements and understandings relating to the subject matter hereof. This agreement shall be binding upon and inure to the benefit of the parties and their respective successors, legal representatives and assigns. The Article of Section headings, if any, of this agreement are for convenience of reference only and do not form a part hereof and do not in any way modify, interpret or construe the intentions of the parties. This agreement shall be executed in one or more counterparts and all such counterparts shall constitute one and the same instrument.

19. This agreement shall be deemed to have been entered into under the laws of the State of and the rights and obligations of the parties hereunder shall be governed and determined according to the laws of said state.

20. No member, individually or collectively, or officer of the University of incurs or assumes any individual or personal liability by the execution of this contract or by reason of the default of the University in the performance of any of the terms hereof. All such liability of members or officers of the University of as such, is hereby released by the Farm Participant, as a condition of and in consideration of the execution of the contract.

IN WITNESS WHEREOF, this agreement has been executed by the parties as of the dates shown below the respective signature.

FARM PARTICIPANT	UNIVERSITY EXTENSION
_____	_____
Print Name	Print Name
_____	_____
Signature	Representative Cooperative Extension Service University of
_____	_____
Date	Date

APPENDIX B

State Final Reports

Illinois
Iowa
Kansas
Minnesota
Missouri
Nebraska
Ohio
Vermont
Virginia

Final Report

September 30, 1982
USDA Cooperative Agreement
No. 12-05-300-419

Solar Heat For Livestock Facilities
Demonstration Project

This report was prepared by C.L. Rahn, Extension assistant and project investigator; A.J. Muehling, Extension agricultural engineer and project manager; and W.H. Peterson, Extension agricultural engineer and associate manager.

The authors would like to express their appreciation to the farmers who participated in this undertaking, without whose cooperation the project could not have been conducted. They allowed us frequent access to their facilities and furnished additional labor and finances to construct and operate their solar demonstration projects. We would also like to thank Illinois Power Company of Decatur, Illinois, for providing electric and gas meters to measure the amount of fuel used during the project, and the Farm and Home Products Division of Growmark, Inc., Bloomington, Illinois, for helping us obtain the L.P. gas meters used during the study.

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The Illinois Cooperative Extension Service provides equal opportunities in programs and employment.

The Demonstration Project

In May, 1979, the Department of Agricultural Engineering through the Cooperative Extension Service at the University of Illinois signed an agreement with The Science and Education Administration - Extension of the United States Department of Agriculture to cooperate for their mutual benefit in an effort to demonstrate the potential of solar energy in providing a significant portion of the heating energy requirments for on-the-farm livestock shelters. Pass-through funds from the Department of Energy (DOE) were made available to establish and demonstrate solar energy heating systems for dairy buildings, poultry brooding buildings, and swine farrowing houses. According to the agreement, The University of Illinois Cooperative Extension Service would:

1. Demonstrate that significant amounts of solar heat can be added to the ventilating air in livestock shelters by incorporating solar energy collectors into the shelters.

2. Evaluate the suitability of various building materials for use in constructing solar collectors in the roof and/or walls of livestock shelters.

3. Determine the approximate savings from the solar heat obtained from livestock shelter solar collectors and the added construction costs and/or extra operating costs.

4. Demonstrate that livestock shelter solar collectors can be used for: (a) heating ventilation air, (b) heating water, and (c) drying crops.

5. Improve the design and develop better plans for constructing solar systems incorporated into livestock shelters, at the same time utilizing accepted energy conservation techniques.

Ten demonstration farms including one dairy farm and nine hog farms, were selected. Almost all of the farms are located in west-central Illinois (Figure 1). We would have preferred farms located over the entire state but because the participating farms had to be chosen over a fairly short period of time, selection was limited to farmers that were already utilizing some solar energy or were planning to add a solar collector to a new or existing livestock building. Because of the influential solar work over the past 20 years of Marvin Hall, University of Illinois Area Adviser, Agricultural Engineering, located at Macomb, Illinois, most of the cooperators are located in this western Illinois area.

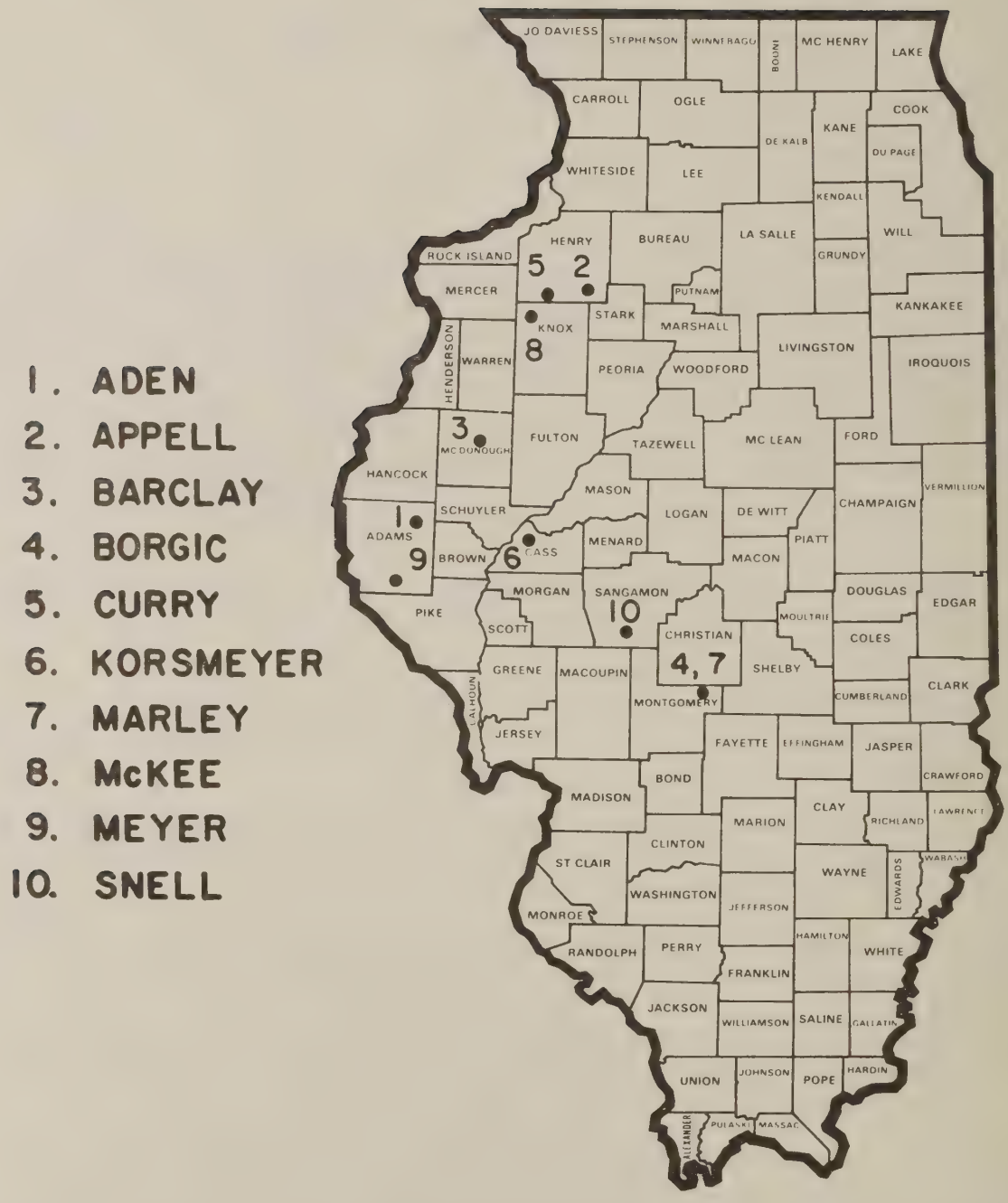


Figure 1. Location of livestock solar heating demonstration projects in Illinois.

Monitoring Procedure

INTRODUCTION

Because of the distant location of the individual demonstration units and the limited amount of monitoring equipment available, it was not felt possible to monitor all projects continuously. It seemed that the best solution to this problem was to selectively monitor all sites at different periods throughout the heating season. The monitoring periods usually ranged in length from one to two weeks. Typically each unit was monitored two times per heating season.

Another limitation, although not a major obstacle, was the potential of spreading disease from one swine production facility to another. It was felt at the beginning of this project that certain precautionary procedures should be followed to reduce the risk to the swine producer. Thanks to the help and guidance of Dr. Leroy Biehl, University of Illinois Extension Swine Veterinarian, the following guidelines were strictly adhered to when visiting the farms and moving instruments from one farm to the next:

1. No two farms were visited during the same day.

2. Clean boots, coveralls, and caps were kept at each farm and used by the person monitoring the solar system.

3. Between visits, all equipment was thoroughly cleaned and then fumigated with ethene oxide.

METHODS

At all locations, the total amount of available solar radiation was measured. The main goal in making the measurements was to determine solar system efficiency. Two data collection methods were followed, either singly or together. A Campbell Scientific digital recorder was used when monitoring the air-type systems while a liquid Btu meter and solar monitor were used on the water-type systems.

VENTILATION AIR PREHEAT

At most of the demonstration projects, solar energy was used to preheat the ventilation air. For these units, the total amount of available radiation was measured with a pyranometer. At some locations more than one surface was being used to receive incoming solar radiation. In these particular cases, two pyranometers were used. The pyranometer was mounted at the same angle as the surface or surfaces intercepting the solar radiation. Total available solar radiation was then determined by calculating the amount of solar radiation for the surface area of the solar collector. Recorded solar data were checked with a

hand held solar meter at the start of each monitoring period. When possible, daily solar radiation measurements were also compared to measurements made by the Illinois State Water Survey.

Air flow and temperature difference (air temperature from solar system minus outside air temperature) were measured to determine the amount of energy delivered by the solar system. Both a propeller anemometer and hot wire anemometer were used to measure the velocity of the air. By knowing the area of the duct used to transfer the air and the velocity at which the air was traveling, the mass flow rate could be determined assuming 13.3 cubic feet of air weighs 1 pound.

Temperatures were measured with copper-constantan thermocouple wire. Again, a thermometer was used to check the recorded data at the time the equipment was set up to begin monitoring.

Since all of these measurements were integrated hourly by the digital recorder, the amount of energy delivered can be calculated, (temperature difference x mass flow rate x specific heat). Dividing this amount by the total available solar energy provides the solar system efficiency value.

WATER-TYPE SYSTEMS

Two of the demonstration projects studied have solar hot water systems. The solar monitor was used to measure total available solar radiation. This monitor stores up to 117 days of solar data in its memory. It can give an instantaneous solar reading, a partial daily integrated readout, or a readout of total solar radiation per day. Again, during equipment setup, the hand- held solar meter was used to check the reading obtained from the solar monitor.

A liquid Btu meter was used to measure the amount of energy actually delivered by the water-type solar collectors. This instrument has the capacity to record total Btu and deliver an instananeous readout of flow, temperature difference, high temperature, and low temperature. It has no memory so daily readings had to be recorded before sunup and after sundown. A thermometer was used to compare the temperature of the water flowing to and from the collector while a timed flowage of water was weighed to check flow rate. These two checks were used as comparisons to the readout from the Btu meter.

After obtaining both the available Btu per day and the amount of energy actually delivered per day, efficiency could be calculated by dividing delivered Btu by available Btu.

INSTRUMENTATION

The following is a list of equipment used to measure and record temperature, air flow, water flow, and solar radiation data.

1. CR5 Digital Recorder
   Data Logger System: Printer, Control module, Power supply, 4 channel millivolt integrator (range 10mV-10V), 4 channel temperature

integrator (range -210°F to +210°F), 10 channel temperature sampler (range -210°F to +210°F).
Campbell Scientific
Logan, Utah

2. LI 200 SB Pyranometer Sensor
   Relative error (±5%)
   Li-COR, Inc.
   Lincoln, Nebraska

3. Gill Propellor Anemometer-Model 27103
   Range 0-70 mph
   Threshold .3-.5 mph
   R.M. Young Co.
   Traverse City, Michigan

4. Thermocouple Wire-Copper/Constantan
   Thermo Electric
   Saddle Brook, New Jersey

5. Liquid Btu Meter
   Threshold 1 gpm
   Natural Power
   New Boston, New Hampshire

6. ETA Hot Wire Anemometer
   Davis Instrument Mfg. Inc.
   Baltimore, Maryland

7. Amprobe Fastemp Thermometer
   Range -50 to 150°F
   Omega Engineering
   Stamford, Connecticut

8. Data Logging System - Solar Monitor
   Integrated Data
   Memory 117 days
   Btu-ft^2 or W/m^2
   Accuracy ±1% at 77°F
   Li-Cor Inc.
   Lincoln, Nebraska

9. 5 Gallon Bucket

10. 50 Pound Scale

11. Solar Meter
    Hand held
    Dodge Products
    Houston, Texas

Determining Long-Term Performance and Payoff of Solar Systems

The main goal of monitoring these solar systems at different times throughout the heating season has been to determine the average efficiency level for each particular system. Once this figure was determined for each collector it was multiplied by the monthly average incident solar radiation striking that collector, for the entire heating season. The heating season was figured as from October through April for heating farrowing rooms and September through May for nursery rooms. If a building contained both farrowing and nursery rooms the calculations were based on the heating season for farrowing rooms. Having multiplied the efficiency level times the available incident solar radiation, we then multiplied again by the area of the collector to determine how much total energy is provided by the solar system during the heating season.

To calculate a simple solar system payback, it is necessary to compare the amount of energy provided by the solar system and the cost of supplying the same amount of energy with a conventional fuel source. The conventional fuel source chosen for comparison was 80-percent efficient L.P. gas selling for $0.60 a gallon. By dividing the total amount of energy provided by the solar system by the amount of energy available in a gallon of fuel and then multiplying by $0.60, we could determine the amount of money saved per heating season by the solar system. Dividing this dollar amount into the original cost of the solar system, shows how many heating seasons it takes to pay off the original cost of the system.

There has been no charge for interest on the investment, but we also have not allowed for any increase in fuel costs or any income tax credits, which would help cancel out the interest charges.

Aden Farm

Adams County, Illinois

GENERAL DESCRIPTION

The Paul Aden farm is located in Adams County in west-central Illinois. The swine farrow-to-finish production unit is 184 by 44 feet, allowing him to produce approximately 2,000 pigs for market each year. The building is divided into a 48 by 44 foot farrowing room with 32 farrowing crates; a 40 by 44 foot nursery room with 20 nursery pens 9 feet 10 inches by 8 feet; and a 96 by 44 foot growing-finishing room with 12 pens 12 feet 2 inches by 8 feet and 12 pens 18 feet 2 inches by 8 feet (see Figures 2 and 3). Supplemental heat is provided by an L.P. gas-fired boiler furnishing hot water floor heat to the farrowing and nursery rooms. Hot water space heat is also available using fin-type, ceiling-mounted, radiator units in these rooms. The building has been insulated with 0.8-inch urethane board in the roof and 3 1/2-inch fiberglass batts in the walls.

The building was constructed in 1977 according to plans from Marvin Hall, University of Illinois Area Adviser, Agricultural Engineering, in western Illinois. The solar system was modified when taken into the Solar Livestock Demonstration Project in 1979.

GOALS

The following objectives governed the design and modifications of this project.

1. To use solar energy to preheat the winter ventilation air -- particularly in the farrowing and nursery rooms.

2. To improve the efficiency of the hot water solar system by modifying the original flow pattern.

3. To plan a ventilation system allowing for minimum operational management.

4. To plan a system that recovers most of the heat normally lost through the ceiling and roof.

SOLAR SYSTEM DESCRIPTION

The swine production building runs east-west and the solar system is located on the roof, which has a 4/12 (18.4°) slope. The west 88 feet of the south-facing roof is a covered plate collector. Clear, corrugated fiberglass covers this portion of the roof. The east 96 feet of the south-facing roof and the entire north-facing roof function as a bare plate collector with steel

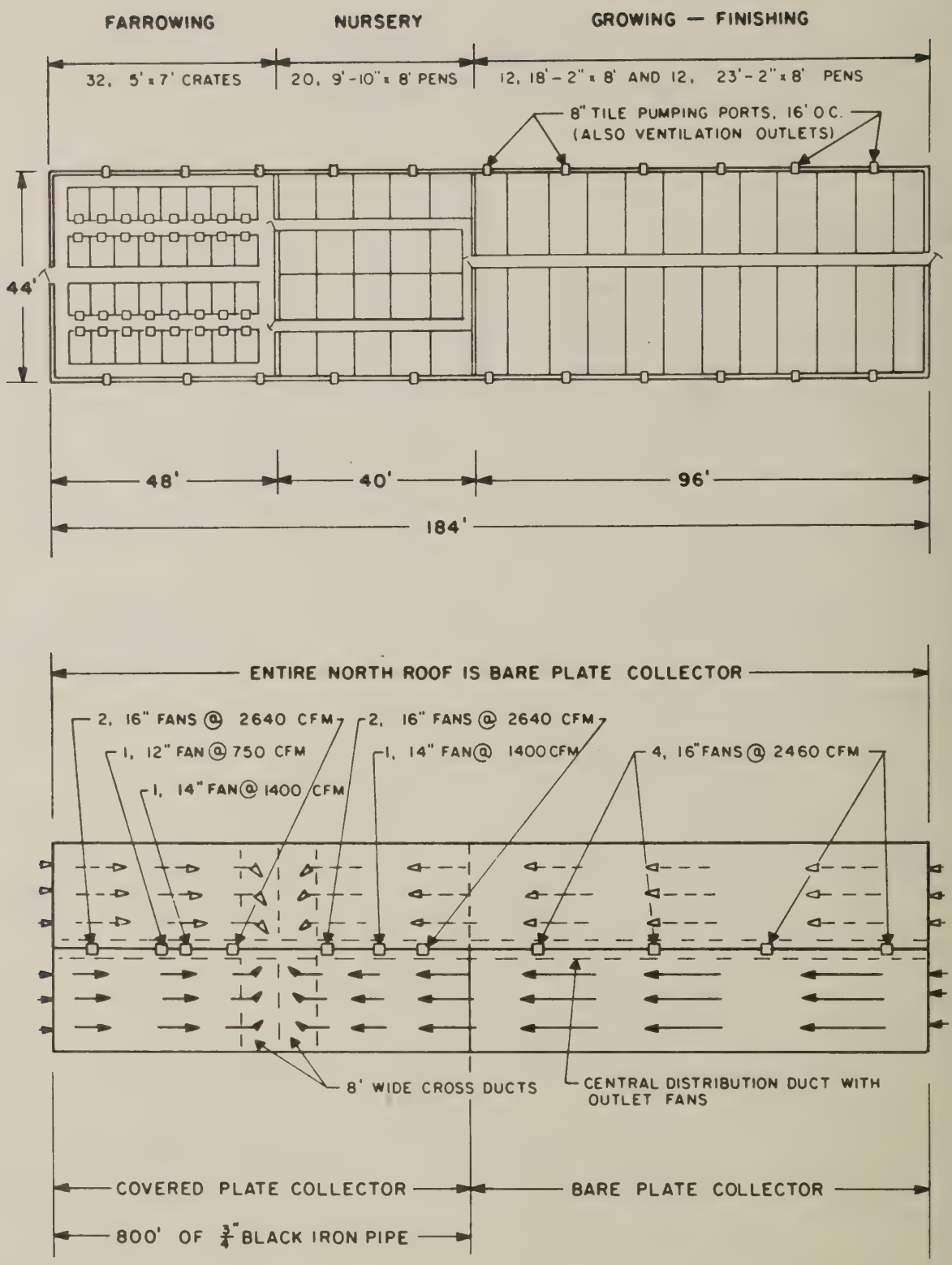


Figure 2. Aden pig production building: plan view (top) showing building arrangement, and top view (bottom) showing airflow pattern in solar collection system.

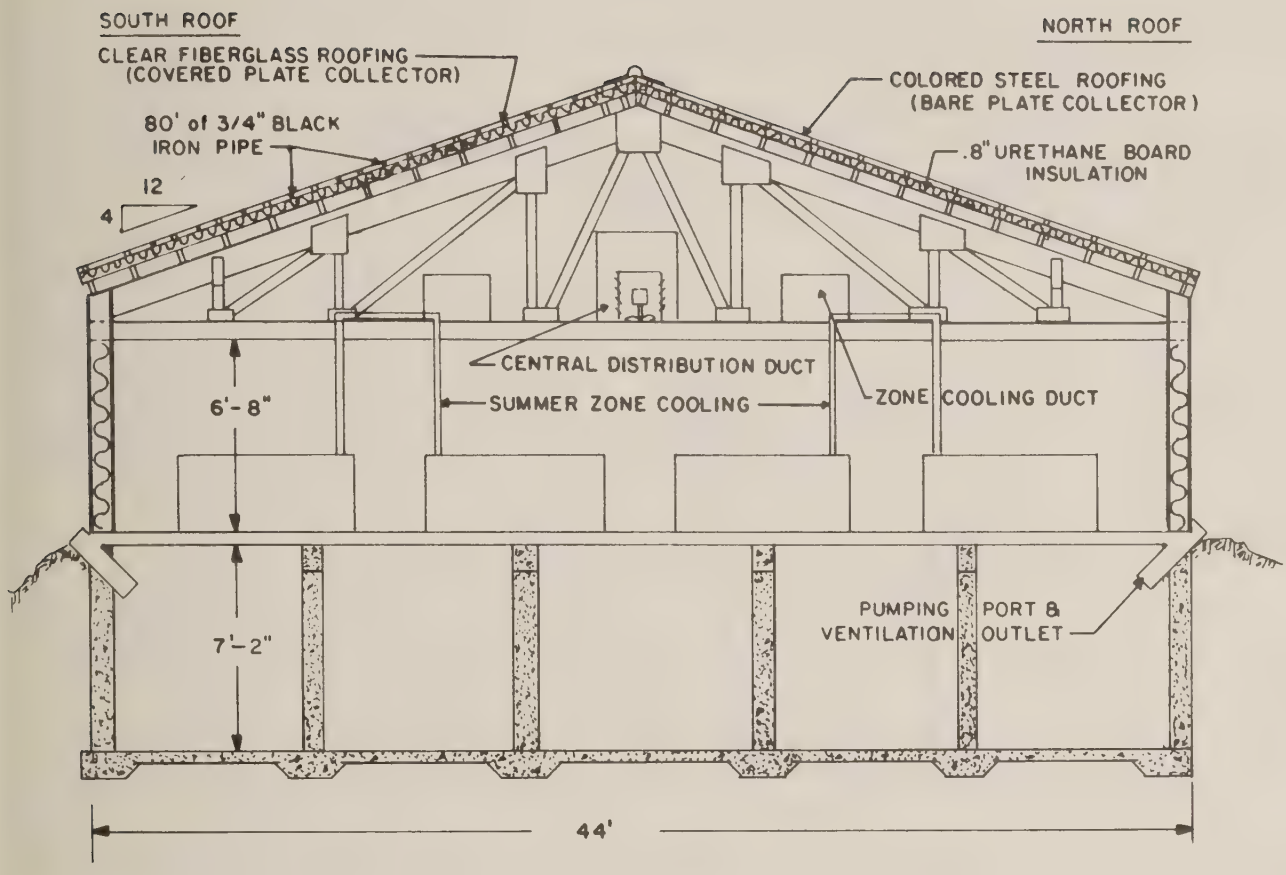




Figure 3. Cross section through Aden farrowing unit, showing solar collector (top), and overall view of Aden pig production building (bottom).

roofing serving as the absorber plate. The top view in Figure 2 shows the air flow pattern through this roof solar system.

Air entering the collector at the west end of the roof passes through the collector that is over the 48 feet of the farrowing room. It is then collected by a cross-duct and directed into a central distribution duct from which fans discharge the air into the farrowing room.

Air entering the bare plate collector at the east end of the south roof passes under the collector for 96 feet over the growing-finishing room before entering the covered plate collector over the nursery room. It then travels 40 feet through the covered plate collector over the nursery room before being intercepted by another cross-duct which directs the air into a central distribution duct. Fans in this distribution duct discharge the air into the nursery and the growing-finishing rooms. The bare plate collectors on the northern part of the roof do not collect much solar heat but do reclaim much of the building heat that manages to escape through the ceiling.

Thermostatically controlled motorized shutters are mounted at both ends of each central distribution duct. These shutters control fresh air and solar heated air to keep the farrowing, nursery, and grower-finishing areas from overheating. This automatically controlled system allows ventilation air to enter either through the solar system where it is preheated or directly from outside, thus, by-passing the solar system. Upper-limit thermostats, which are set by the operator, allow heated air to enter through the motorized shutters mounted adjacent to the cross duct from the solar system until the temperature in the rooms becomes too high. Once this occurs, these motorized shutters close and the other motorized shutters mounted on the outside ends of the central distribution ducts open allowing outside air to enter the ventilation systems. When the temperture in the rooms falls below the set temperature on the thermostat the sequence is again reversed.

The south roof covered plate collector, which is over the farrowing and nursery rooms, has 800 feet (10 lines, 80 feet long) of 3/4-inch black iron pipe mounted in the air channels. The pipes were an attempt to heat water using solar energy. Originally the pipes were connected in series and were ineffective. Fiberglass roofing sheets were taken off at each end of the pipe arrangement and the pipes were reconnected in parallel with hopes of improving performance. Because of limited space in the roof, only a 1-inch manifold could be fitted into the existing space, which somewhat limited flow through the pipe.

SOLAR SYSTEM COST

The added cost of the solar portion of the building was $3,238. This did not include any of the small extra costs for making the portion of the roof that is a bare plate collector. For the covered plate collector, this amounts to a cost of $1.53 per square foot of collector. A listing of costs is shown below:

Fans, Dampers, and Thermostats	$1,535.07
Plumbing	564.93
Electrical	332.40
Fiberglass cost minus metal Roofing cost (2,112 ft^2)	105.60
Estimated Labor	700.00
	$3,238.00

SOLAR SYSTEM PERFORMANCE

We began monitoring the solar system on the Aden farm during the winter of 1980-81. Because of instrumentation constraints, we could monitor only the part of the system above the farrowing room.

Air temperature, ventilation air flow, and solar radiation were monitored for the period of January 13-25, 1981, and January 5-18, 1982. From these measurements, we calculated the system added slightly more than 4.25 million Btu of heat energy to the ventilation air entering the building during these 27 days. Total radiation over this same period was around 22.5 million Btu. This was calculated to be an efficiency of 19 percent. At this rate the heat collected is equal to 1,363 gallons of L.P. gas per heating season. A simple payback, not charging for interest on the $3,238 investment, would be about four heating seasons.

The figures obtained from monitoring this solar ventilation system need to be viewed as results of a combined solar heating and heat reclamation system. With only 0.8 inch of urethane insulation in the roof, some heat is lost through the ceiling and is recaptured by the ventilation air moving through the collector on both sides of the roof. Therefore, all the air passing through the collectors was influenced both by the solar radiation and the heat loss from the building.

The performance curves for January 6 and 7 of 1982 show the effects of both factors (see Figure 4). The effect of heat reclamation is vividly depicted by the amount of temperature rise of the ventilation air passing through the solar collector. Especially notice the rise in temperature during the nonsolar periods between 6:00 p.m. and 8:00 a.m. There was as much as a 10° F rise in the air coming from the collector when the sun was not shining. This temperature increase can be attributed to heat reclamation.

The water flow pattern of the 800 feet of 3/4-inch black iron pipe located in the air space of the covered plate collector was changed from series to parallel. Because of limited space under the fiberglass, only a 1-inch manifold could be fitted into the existing space, which somewhat limited flow through the system. Measurements during the winter period showed that the hot water collector still delivered no useable energy to the hot water heating system.

SUMMARY

Because of the low initial cost of installing this solar system and the consistent performance level of the solar ventilation air preheat, the system has

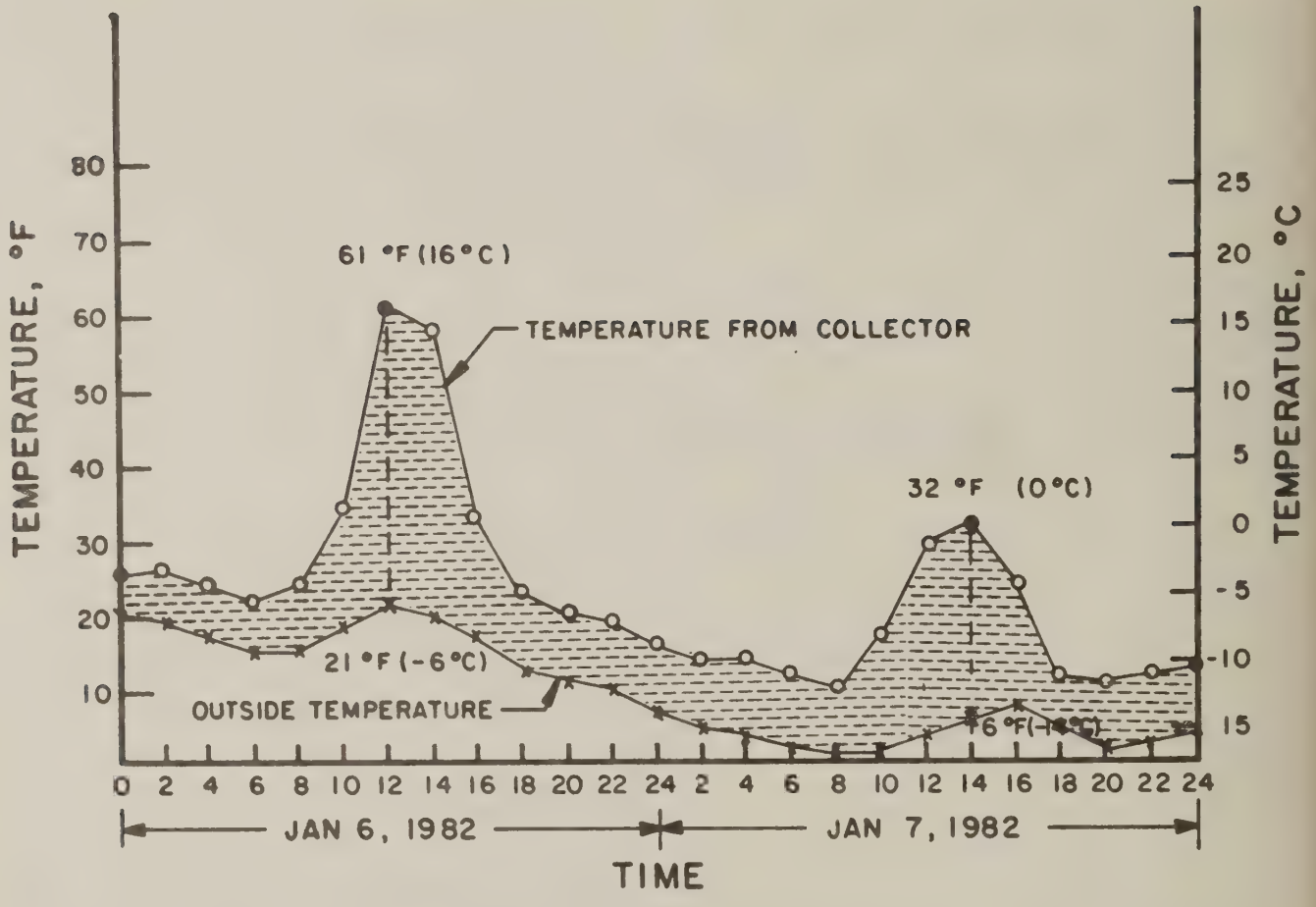


Figure 4. Heat delivered by Aden solar system to farrowing unit, January 6 and 7, 1982.

been shown to have an extremely quick payoff time of four heating seasons. It is not clear, however, just how much of the payoff is attributed to the collection of solar energy and how much to the reclamation of heat escaping through the roof. The only way to determine this value would have been to increase the amount of insulation in a duplicate building until the heat reclamation came to a halt and compare the costs and benefits.

Since some of the solar cost resulted from constructing the water heating portion of the solar system, which never delivered any energy to the building, the time required to pay off the solar system could have been reduced even further without the water system.

Even after the ten water lines were changed from series to parallel in the covered plate collector, the hot water system failed to function. Following are possible reasons:

1. The ventilation air was constantly passing through the same area in the covered plate collector where the pipes were mounted and may have removed the heat away before the water in the pipes could warm up sufficiently.

2. The 800 feet of black iron pipe does not have fin-type absorber plates soldered to it as do most commercial units. They do not actually offer much surface area for the sun's rays to make contact.

3. For the water system to be activated, the temperature of the water had to exceed 120°F. This is a temperature level expected from a commercial water type solar collector but not from black iron pipe mounted in an air channel.

The final goal was to design and construct a system that would require a minimum amount of management by the operator. By utilizing thermostats to control all of the fans and dampers in the system, the only required management is to set, check, and maintain the thermostats, fans, and dampers.

CONCLUSIONS

This system of preheating ventilation air seems to offer a reasonable return on the added investment.

Black iron pipe without absorber fins does not seem to provide a workable solar water heating system in this configuration.

The reworked ventilation system, with automatic instead of manual switchover between solar and nonsolar ("summer") mode, works well and appreciably reduces the time spent in attending the system in mild weather.

This solar system does recover substantial amounts of the heat loss through the poorly insulated ceiling.

PERFORMANCE DATA

Solar System Efficiency Level: 19%

Collector Size: 2,112 ft^2 (Only covered plate collector)

Solar System Cost: $3,238

Assumptions

1. Temperature of ventilation air to farrowing room needed to achieve comfort zone -- 68°F

2. Heating season (HS) is October through April

3. L.P. gas as an average conventional fuel source provides 73,600 Btu/gal

4. On a south-facing 4/12 sloped roof, approximately 250,000 Btu/ft^2 are available from October through April

5. 1 gal of L.P. gas costs $0.60

Payback Calculation

$$\frac{250{,}000 \text{ Btu}}{\text{ft}^2\text{-HS}} \times .19 \times 2{,}112 \text{ ft}^2 \times \frac{1 \text{ gal L.P.}}{73{,}600 \text{ Btu}} = 1{,}363 \text{ gal L.P./HS}$$

$$\frac{1{,}363 \text{ gal L.P.}}{\text{HS}} \times \frac{\$0.60}{\text{gal L.P.}} = \$817.80/\text{HS}$$

$$\frac{\$3{,}238}{\$817.80/\text{HS}} = 3.96 \text{ or } 4 \text{ heating seasons until payback}$$

Appell Farm

Henry County, Illinois

GENERAL DESCRIPTION

The Paul Appell farm is located in Henry County in northwestern Illinois. A turkey processing plant has been converted into a farrowing-nursery facility that is part of a production unit where approximately 9,000 hogs are produced each year.

A new grain-storage and solar-drying facility has been built next to the swine production system. Solar-heated air from the drying facility is also being ducted to the swine production facility to be used as ventilation air in the farrowing and nursery rooms.

This solar system is generally called a bin-in-building drying system. The south wall and roof of the 116-by-44-foot pole building are covered with clear fiberglass roofing (see Figure 5). Two 20,000-bushel drying bins are housed in 96 feet of the building. A ceiling and wall partition off a 20-foot shop and feed mill section on the east end. Since the drying bins are inside the building, they don't require a roof.

To utilize the solar energy collected during non-drying times of the year, a 2-by-2-foot overhead insulated duct extends to a hog building 85 feet away from the grain-drying building. The duct is insulated with 2 inches of expanded polystyrene insulation board.

GOALS

The main goal of the solar system is to provide low cost solar heat for low temperature grain drying in the grain bins. A second goal is to utilize some of the collected solar energy to preheat ventilation air for the farrow and nursery rooms in the hog production unit.

SOLAR SYSTEM DESCRIPTION

To collect solar energy in the grain storage building, clear fiberglass was substituted for metal roofing and siding both on the south facing roof and the 18-foot high south sidewall. Air enters the building through a screened inlet along the bottom of the south wall. This inlet is not located on the shop portion of the building. The winter sun, which has a desirable angle to the vertical wall, shines through the clear fiberglass roof and wall, warming the inside air as well as other objects it shines on -- bins, concrete floor, etc. In the grain-drying cycle, air entering the building is warmed during the day. The 20-horsepower grain-drying fans pull this air from the top of the bins, down through the corn, and exhaust the air out the north side of the building. When heated air is being collected for use in the hog building, a fan in the overhead

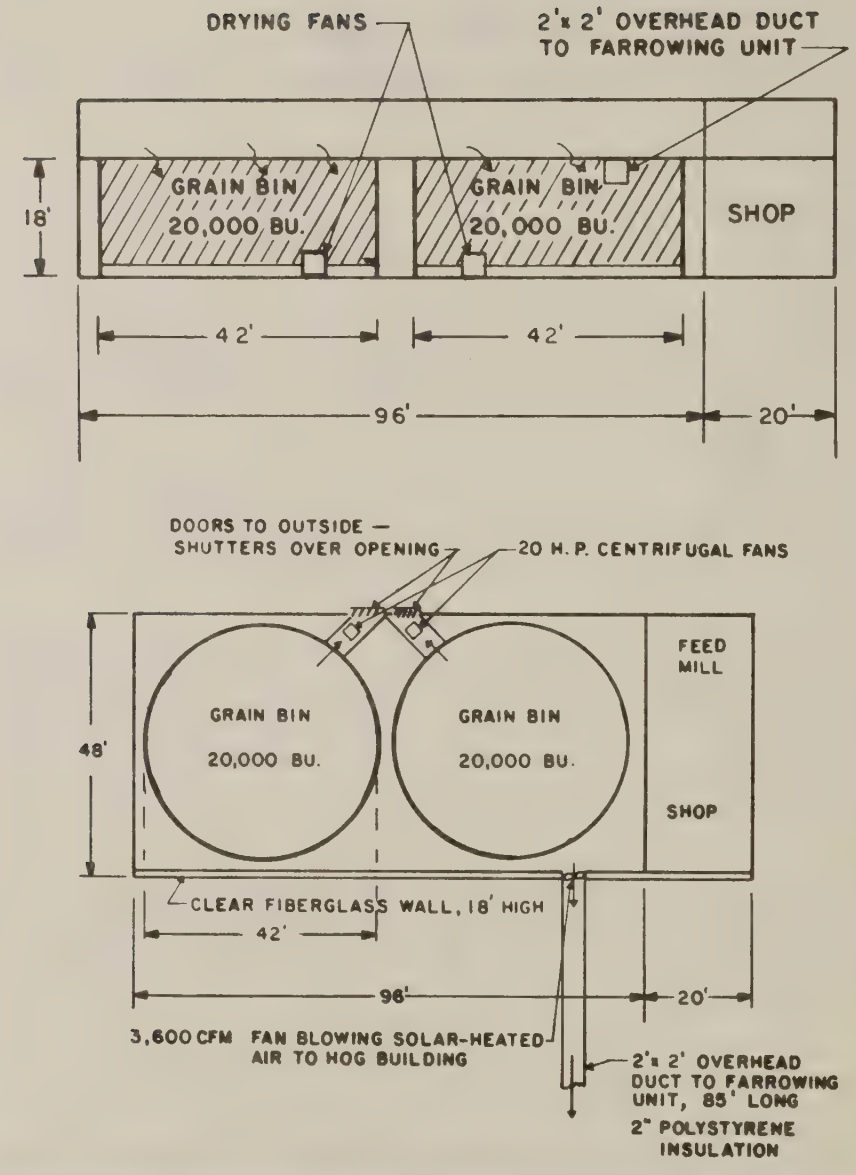




Figure 5. Appell bin-in-building solar grain drying unit: top view (top), side view (middle), and view showing ventilation duct to nearby farrowing-nursery building (bottom).

duct delivers about 3,600 cubic feet per minute of air to the attic of the farrowing room, from where it is distributed through the farrowing ventilation system. To collect the warmest air, a plastic collection duct was run from the fan in the overhead duct to the peak of the center of the building.

SOLAR SYSTEM COST

The only extra cost for heating the ventilation air for the hog production unit was $2,200, which was the cost of the 85-foot long overhead duct. A breakdown of these costs is as follows:

Material	$1,400
Labor	700
Fan	100
	$2,200

SOLAR SYSTEM PERFORMANCE

We began monitoring the solar system during the winter of 1980-81. Since the amount of air being delivered from the solar bin-in-building to the hog building was at a constant rate of about 3,600 cfm, the only variables measured while monitoring were outside temperature, temperature of air moving through the duct, and the amounts of available solar radiation striking the roof and wall. These measurements were taken as integrated values at one-hour time intervals. The periods over which monitoring occurred were November 4-10, 1980; and Febuary 10-16, 1981. Figure 6 shows the small amount of heat ducted to the nearby building for two days in November, 1980. This maximum of 11°F rise was disappointing because solar attics usually produce temperature rises of 30° to 50°F. We suspect the air collection system did not collect the warmest air in the building. From our measurements, we calculated the system added slightly more than 2 million Btu of heat energy to the ventilation air entering the attic of the hog building during these 14 days. The total amount of available solar radiation striking the roof and wall of the grain storage unit during this period was around 65 million Btu. This was calculated to be an overall efficiency of only 3 percent for the heat being ducted over to the nearby building. At this rate, the heat collected would be equal to 453 gallons of L.P. gas per heating season from October through April. A simple payback not charging for interest on the $2,200 invested in the duct and fan would be about eight heating seasons.

One of the factors involved in system payoff which we were unable to measure is longevity of the duct. Separation was beginning to occur along the sealed joints where the pieces of plywood making up the duct joined together. It is unknown as to how long it will be before air will begin to leak out of the duct and lower the system's efficiency. The problem appears to be due to the fact that the duct had to be constructed 18 feet above the ground so that tractor trailers could pass underneath. At this height, the duct which is 2 feet square and 85 feet long sways and buckels in the wind which has caused those separations at the joints. There is a further need to observe the duct over a longer period to see the long-term effect on the duct's ability to deliver air from the bin-in-

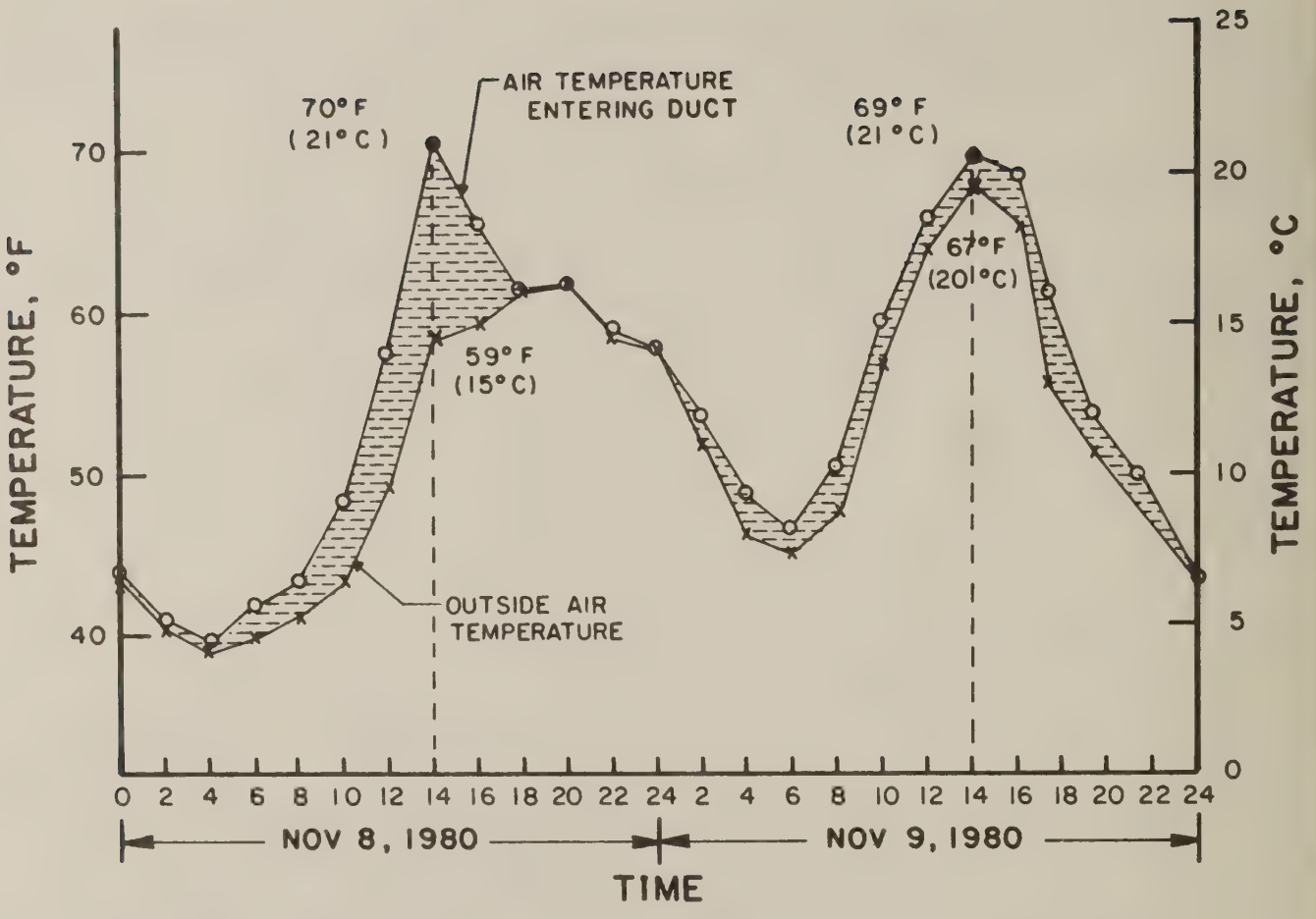


Figure 6. Heat from Appell solar system entering duct to nearby farrowing-nursery unit, November 8 and 9, 1980.

building to the hog structure. An underground duct might have been more satisfactory but would have cost more to install.

SUMMARY

When this project began, Paul Appell was already successfully using solar energy generated in his solar bin-in-building to provide economical heat for low-temperature grain drying. At the beginning of this project, the goal was to construct an inexpensive duct from his solar bin-in-building to his farrowing-nursery hog production unit so that he could utilize some of the collected solar energy to preheat ventilation air for this building.

The one limiting factor raising the costs and reducing the probable life of the 85-foot long insulated duct is wind stress. The duct had to be constructed 18 feet off the ground so tractor trailers could pass underneath resulting in considerable stress in the duct. Even with this drawback, the $2,200 duct should transfer enough heat to pay for itself in eight years.

The system could be improved if black painted plywood had been placed on the south wall in back of the posts. This would have provided a solar absorption surface behind the clear fiberglass. It would have been necessary to check the airflow area available in the wall during grain drying when the airflow rate is increased considerably. It would require one square foot of cross section area for every 1,000 cubic feet of air movement.

CONCLUSION

This system, as constructed, provided a marginal payback at current energy costs. The system would work better if warmer air could be produced and an air-tight duct could be provided.

PERFORMANCE DATA

Solar System Efficiency Level: 3%*

Roof Collector Size: 2,935 ft^2
Wall Collector Size: 1,728 ft^2

Duct Cost: $2,200

Assumptions

1. Temperature of ventilation air to farrowing room needed to achieve comfort zone -- 68°F
2. Heating season (HS) is October through April
3. L.P. gas as an average conventional fuel source provides 73,600 Btu/gal
4. On a south-facing 4/12 sloped roof, approximately 250,000 Btu/ft^2 are available from October through April
5. On a south-facing wall, approximately 219,000 Btu/ft^2 are available from October through April
6. 1 gal of L.P. gas costs $0.60

Payback Calculation

Roof

$$\frac{250{,}000 \text{ Btu}}{ft^2\text{-HS}} \times .03 \times 2{,}935 \text{ } ft^2 \times \frac{1 \text{ gal L.P.}}{73{,}600 \text{ Btu}} = 299 \text{ gal L.P./HS}$$

*This solar system efficiency level was only for the small amount of solar energy transferred across to the nearby farrowing-nursery building.

Wall

$$\frac{219{,}000 \text{ Btu}}{\text{ft}^2\text{-HS}} \times .03 \times 1{,}728 \text{ ft}^2 \times \frac{1 \text{ gal L.P.}}{73{,}600 \text{ Btu}} = 154 \text{ gal L.P./HS}$$

$$\frac{299 \text{ gal L.P.}}{\text{HS}} + \frac{154 \text{ gal L.P.}}{\text{HS}} = 453 \text{ gal L.P./HS}$$

$$\frac{453 \text{ gal L.P.}}{\text{HS}} \times \frac{\$0.60}{\text{gal L.P.}} = \$271.80/\text{HS}$$

$$\frac{\$2{,}200}{\$271.80/\text{HS}} = 8.1 \text{ or } 8 \text{ heating seasons until payback}$$

Barclay Farm

McDonough County, Illinois

GENERAL DESCRIPTION

The Scott Barclay farm is located in west-central Illinois in McDonough County. The 48-by-248-foot swine farrow-to-finish production unit is an in-line building containing four farrowing rooms, four nursery rooms, a warm grower section and a 144-foot long growing-finishing section (Figures 7 and 8). The south wall of the 80-foot farrowing and nursery section is a covered plate collector with clear fiberglass over a 6.5-inch air space. A solar attic extends over the west 104 feet of the south roof. The south half of the solar attic is partitioned off with insulation board as shown in the cross section in Figure 8. The remaining 144 feet of the south roof has a covered plate collector with only a 1 1/2-inch air space under the fiberglass roofing.

GOALS

The major goals governing the design and construction of this system are:

1. To use solar energy to preheat the ventilation air -- particularly for the farrowing and nursery rooms.

2. To also provide some solar heat to the growing-finishing section.

3. To provide a heat storage for excess heat collected by the solar collector.

4. To plan a system requiring minimum operational management.

SOLAR SYSTEM DESCRIPTION

Air enters the solar wall through a slot at the bottom of the wall and moves up the solar wall and into the solar attic. Air enters the covered plate collector through the 1 1/2-inch spacing at the far east end of the roof and moves the entire 144 feet through these narrow air channels before entering the solar attic over the farrowing and nursery rooms.

Once the air is in the solar attic, the preheated ventilation air has two routes it can follow. Fans mounted on the outside walls of the farrowing and nursery rooms create negative pressure which pulls the air down a duct located at the west end of the solar attic into the central aisle from where it is distributed to the farrowing and nursery rooms through a ventilation slot at the top of the walls on both sides of the central aisle. A central duct with fans in it also runs from the solar attic through the growing-finishing section. When these duct fans run, they also pull warm air from the solar attic and distribute it through the growing-finishing section of the building.

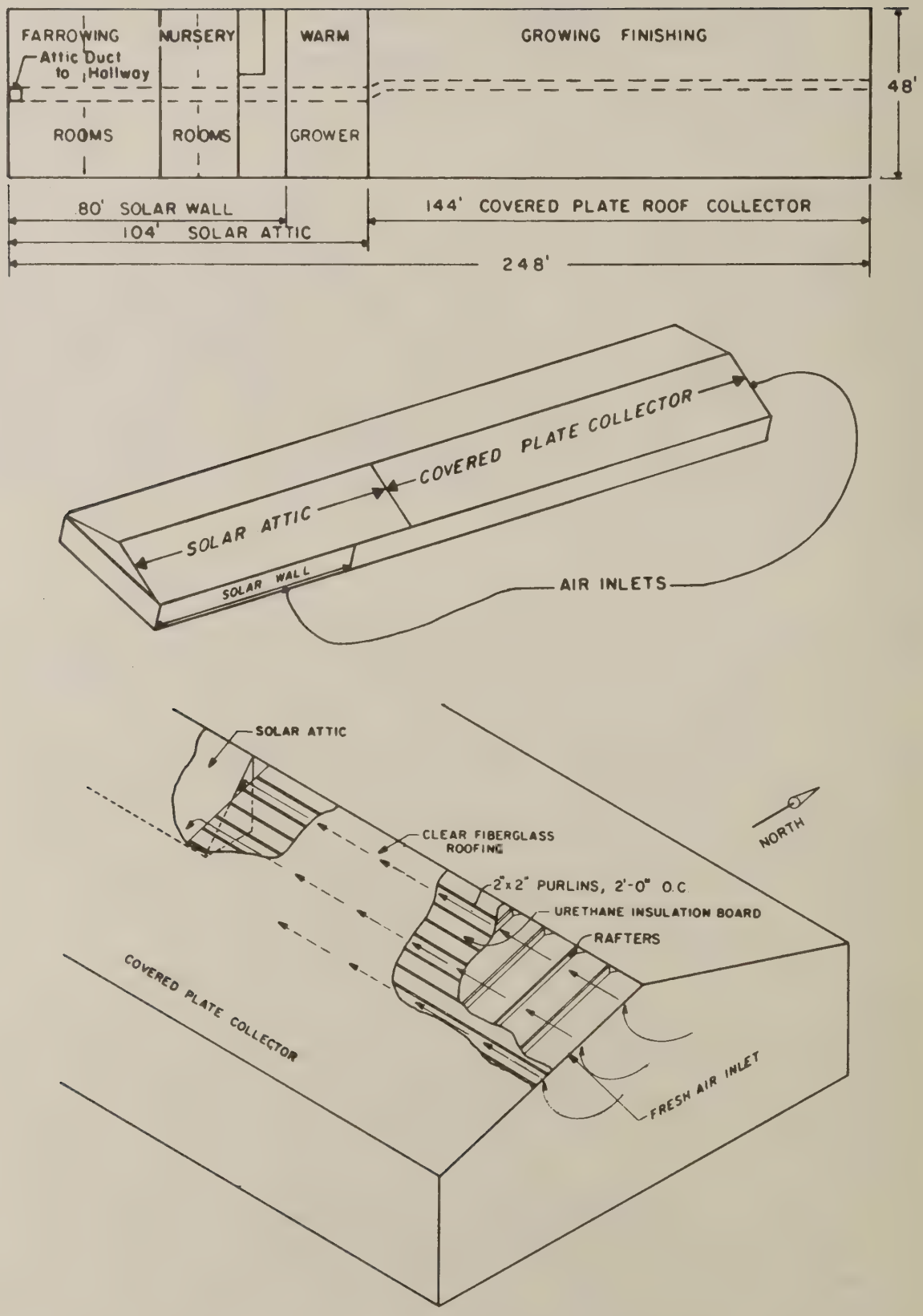
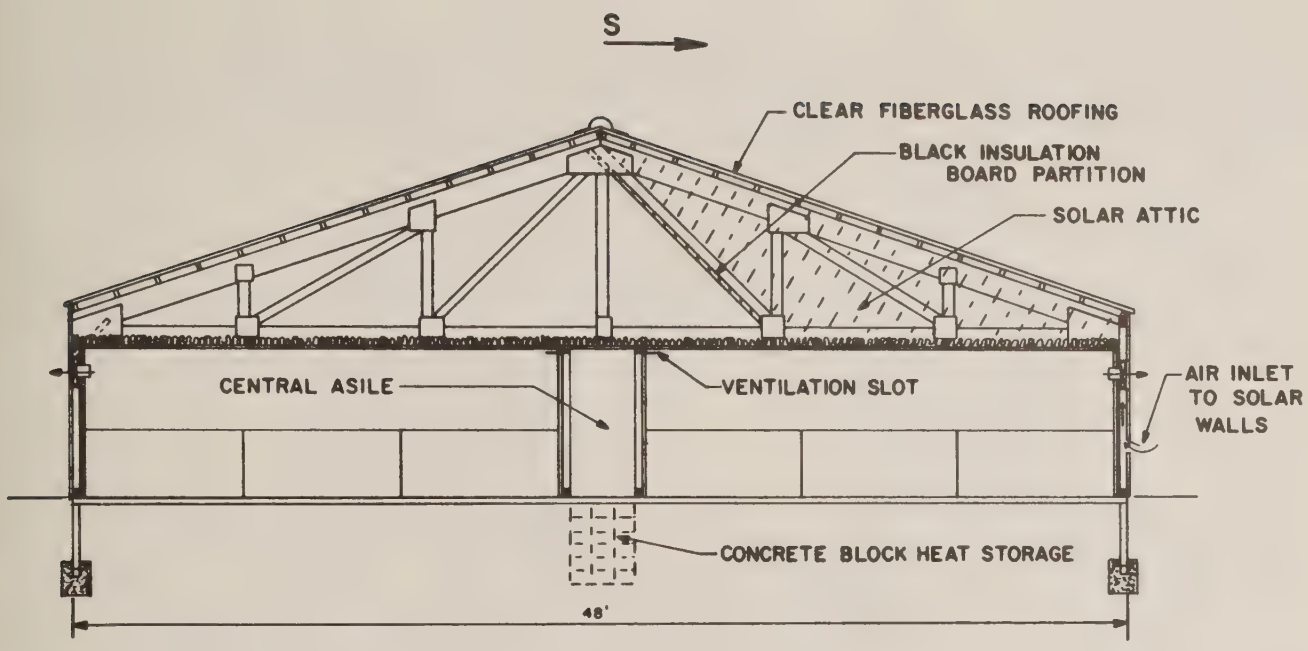


Figure 7. Barclay pig production unit: plan of building (top), arrangement of solar collection system (middle), and airflow pattern through solar collector system (bottom).



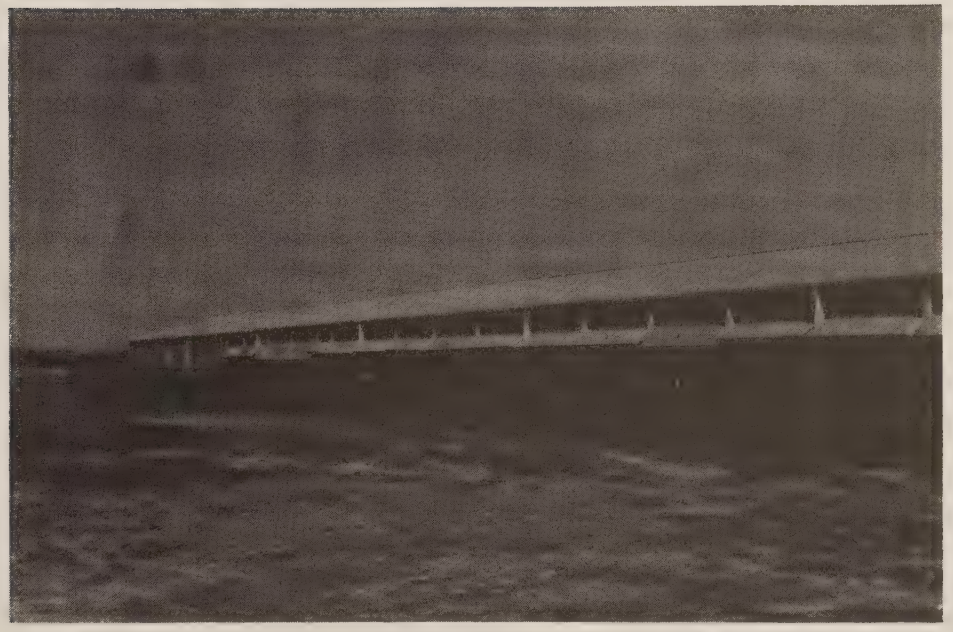


Figure 8. Barclay pig production unit: cross section through solar attic in nursery section (top), and view of building with farrowing-nursery section at far left end (bottom).

The 6.5-inch air space in the solar wall offers less resistance to air flow than the air being pulled through the long 1 1/2-inch air channels of the covered plate roof collector. Thus, most of the air is pulled up through the wall as opposed to coming through the narrow covered plate roof collector.

SOLAR SYSTEM COST

The cost of the solar portion of the building is $8,228. This breaks down to a cost of $1.23 per square foot of collector.

SOLAR SYSTEM PERFORMANCE

The solar system on the Barclay farm was monitored during the winter of 1980-81. Air temperatures, ventilation air flow, and solar radiation levels were measured during the periods of December 18, 1980 - January 6, 1981; and March 11-16, 1981. From these measurements, calculations were made which showed the solar system added approximately 26 million Btu of heat energy to the ventilation air during these 26 days. The total amount of available solar radiation striking the roof and wall during this period was slightly more than 320 million Btu. This was calculated to be an efficiency level of only 8 percent. At this rate, the heat delivered by the solar system would be equal to 1,744 gallons of L.P. gas per heating season (October through April). A simple payback not charging for interest on the $8,228.00 investment would be about eight heating seasons.

The one large inlet from the attic to the hallway at the west end of the hallway does a poor job of distributing the ventilation air into the hallway. By having more inlets, a greater degree of control could be maintained over the total inlet area during periods of reduced air movement. With the one large air inlet, back drafts can and do occur during periods of low air movement. This phenomenon can be seen in Figure 9, which shows that during the night, the temperature of the air from the attic was higher than expected due to the back draft of air from the rooms below. This warm air was also carrying moisture which condensed in the attic and caused some moisture problems.

SUMMARY

When this building was first constructed, a solar system was included as part of the design. The goals when incorporating the solar system into the building were to:

1. Provide a method of preheating the ventilation air used in the farrowing and nursery section of the building.

2. Supply some solar-heated air to the growing-finishing area.

3. Plan a system with minimum management requirements.

4. Devise a system for storing solar heat.

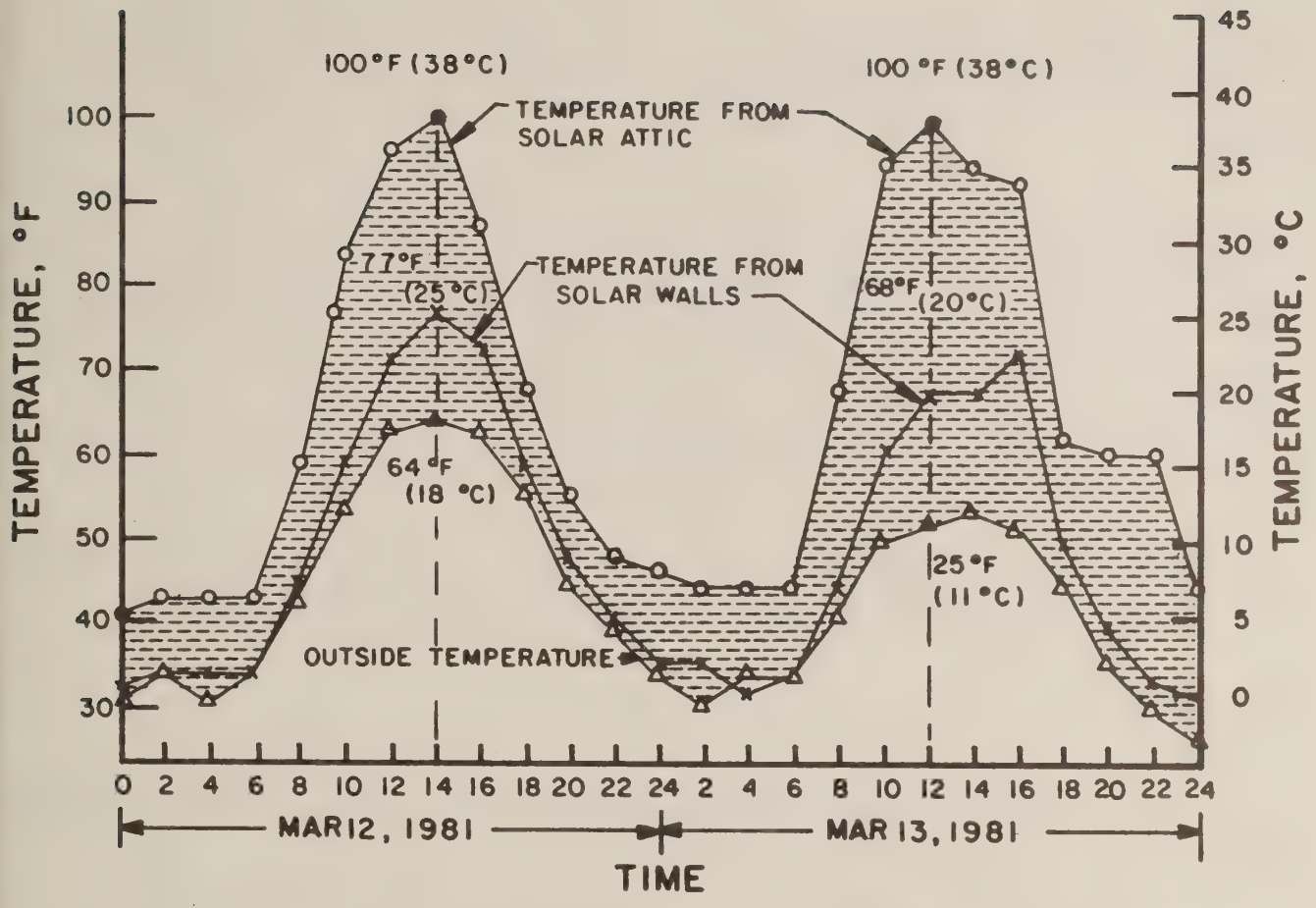


Figure 9. Performance of Barclay solar system in farrowing-nursery section, March 12 and 13, 1981.

The solar system has supplied preheated ventilation air to both the farrowing-nursery area and the growing-finishing area. According to calculations based on measurements, the amount of energy supplied by the solar system per heating season is equivalent to the energy available from 1,744 gallons of L.P. gas. At this rate, the solar system should provide enough heat for simple payback to occur on the initial investment in eight years.

Three aspects of the buildings' construction could be changed to improve the performance of the solar system. The first change would be to increase the number and positioning of the inlets from the solar attic to the hallway of the farrowing and nursery section. As it now exists, the one large inlet from the attic at one end of the hallway does a poor job of distributing the ventilation air into the hallway. It also allows a back draft to occur when air movement is slow. The warm air in the back draft carries moisture that condenses in the attic and causes some moisture problems. Having more inlets would not only improve distribution of ventilation air but would also permit better control over the total inlet area during periods of reduced air movement.

The second change would be to increase the 1 1/2-inch depth of the air channel in the roof covered plate collector. Moving air 144 feet through a 1-1/2-inch air space creates too much static pressure. If anything, more air should move through the roof than the wall covered plate collector because it is larger.

The final change involves the heat storage system. When the building was constructed, 100 tons of concrete blocks were laid under the center aisle in the farrowing-nursery area. The plan was to circulate excess heat from the solar attic down through the blocks and back up into the solar attic via air ducts at each end of the solar attic. Once in the blocks, the heat was to radiate up through the floor warming the ventilation air before it entered the farrowing and nursery rooms. However, the producer never installed the needed ducts, fans, and controls. Thus, the concrete blocks increased the cost of the solar system while providing no benefit to the heating system up until this time.

The final goal was to minimize the management of the system. Since all air movement is controlled by thermostats, the only required management would be to set, check, and maintain the thermostats, fans, and motorized shutters.

CONCLUSIONS

The economic feasibility of this sytem, as constructed and operated, was adequate for today's energy costs, but would have been improved if the expense of the unused heat storage had not been incurred.

The solar collector inlets need to be better balanced to equalize the friction loss between the roof and the wall collectors.

PERFORMANCE DATA

Solar System Efficiency Level: 8%

Roof Collector Size: 6,000 ft^2
Wall Collector Size: 480 ft^2

Solar System Cost: $8,228

Assumptions

1. Temperature of ventilation air to farrowing room needed to achieve comfort zone -- 68°F
2. Heating season (HS) is October through April
3. L.P. gas as an average conventional fuel source provides 73,600 Btu/gal
4. On a south-facing 4/12 sloped roof, approximately 250,000 Btu/ft^2 are available from October through April
5. On a south-facing wall, approximately 219,000 Btu/ft^2 are available from October through April

6. 1 gal of L.P. gas costs $0.60

Payback Calculation

Roof

$$\frac{250{,}000 \text{ Btu}}{\text{ft}^2\text{-HS}} \times .08 \times 6{,}000 \text{ ft}^2 \times \frac{1 \text{ gal L.P.}}{73{,}600 \text{ Btu}} = 1{,}630 \text{ gal L.P./HS}$$

Wall

$$\frac{219{,}000 \text{ Btu}}{\text{ft}^2\text{-HS}} \times .08 \times 480 \text{ ft}^2 \times \frac{1 \text{ gal L.P.}}{73{,}600 \text{ Btu}} = 114 \text{ gal L.P./HS}$$

$$\frac{1{,}630 \text{ gal L.P.}}{\text{HS}} + \frac{114 \text{ gal L.P.}}{\text{HS}} = 1{,}744 \text{ gal L.P./HS}$$

$$\frac{1{,}744 \text{ gal L.P.}}{\text{HS}} \times \frac{\$0.60}{\text{gal L.P.}} = \$1{,}046.40/\text{HS}$$

$$\frac{\$8{,}228}{\$1{,}046.40/\text{HS}} = 7.9 \text{ or } 8 \text{ heating seasons until payback}$$

Borgic Farm

Montgomery County, Illinois

GENERAL DESCRIPTION

The Erval Borgic farm is a grain and hog farm located in Montgomery County in central Illinois. The entire hog production system is comprised of several buildings capable of producing approximately 4,500 hogs per year. The Borgics had been using solar energy long before this project began. A farrow-nursery building constructed on their farm in 1974 utilizes solar collectors to preheat the ventilation air.

The confinement nursery building studied in this demonstration project is used for pigs from weaning to about 50 pounds. It is a commercial factory-built building, which was moved to the site and set on top of a foundation. Measuring 20 by 50 feet, the building is divided into four rooms (see Figures 10 and 11). Each room has six 4-by-8 1/2-foot pens capable of holding two litters each (16 to 18 pigs). The building houses a total of 400 young pigs. The central air distribution duct is located over the central aisle.

Plastic trays under the pen floors fully slotted with plastic coated expanded metal catch the manure from the pigs. The liquid manure is drained into a deep storage pit under the adjoining finishing building.

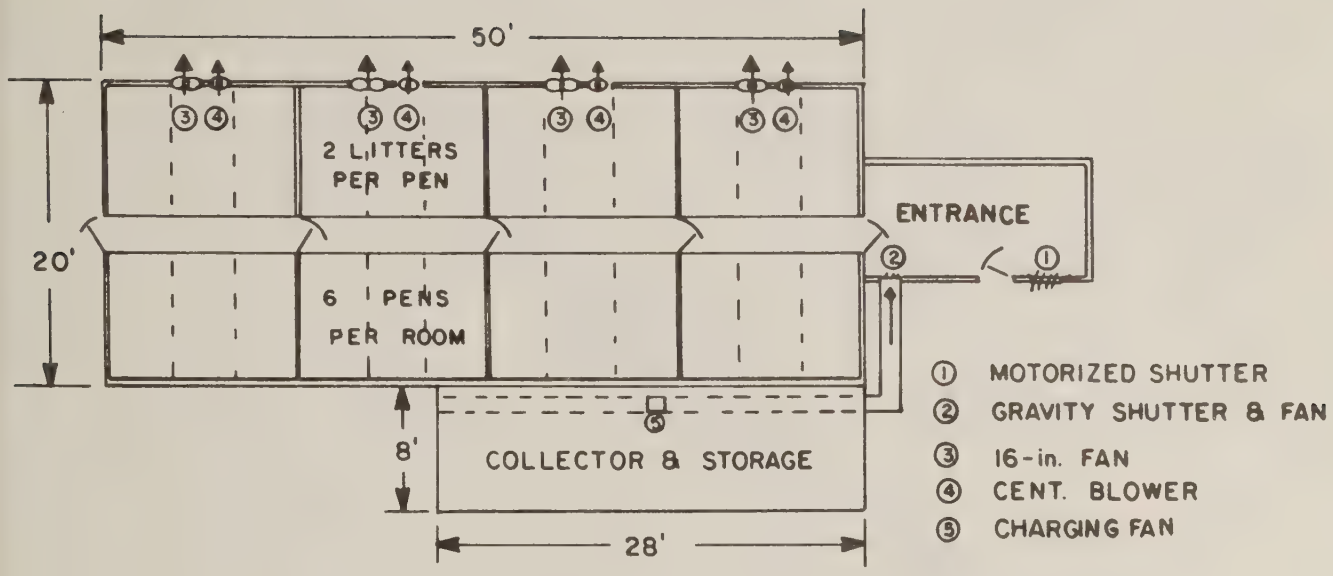
GOALS

The following objectives governed the design and construction of this solar system:

1. To provide a solar collector that would preheat the ventilation air.
2. To establish a heat storage for use when the sun is not shining.
3. To develop and evaluate a solar collector with storage that could be added to any existing or planned livestock building.

SOLAR SYSTEM DESCRIPTION

The 28-foot-long, triangular-shaped solar collector and rock storage was built on the south side of the nursery building (see Figures 10 and 11). To minimize construction costs, a triangular-shaped depression was made in the earth to a depth of about 3 feet for the rock heat storage. An 18-inch diameter perforated metal aeration duct extends along the length of the excavation and is used for air distribution beneath the rock. At the center of the storage, the metal aeration duct coming from both directions opens into a 2-by-2-foot plywood vertical duct. Rocks approximately 4 inches in diameter are piled over the aeration duct so as to provide nearly equal distance for airflow between all



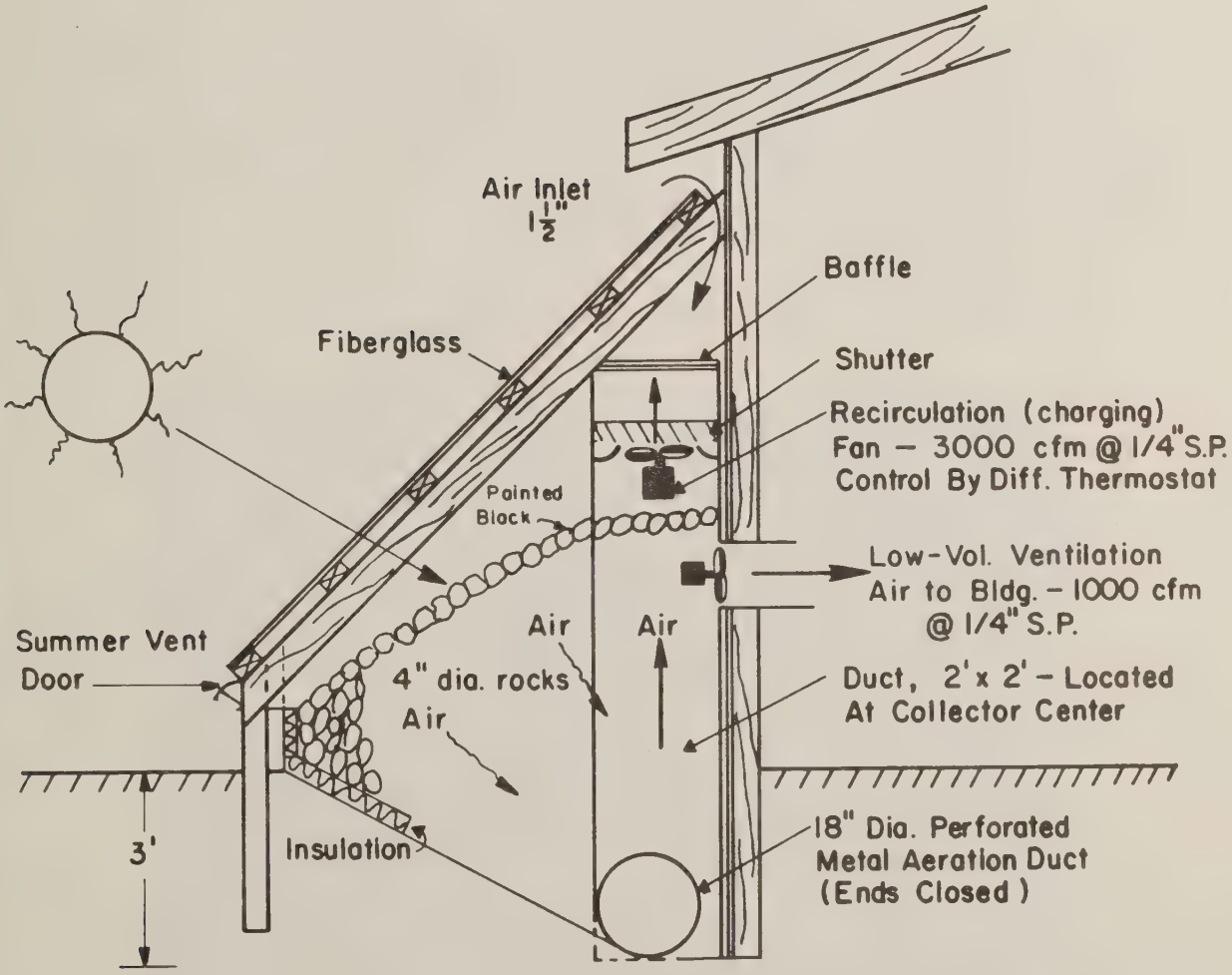
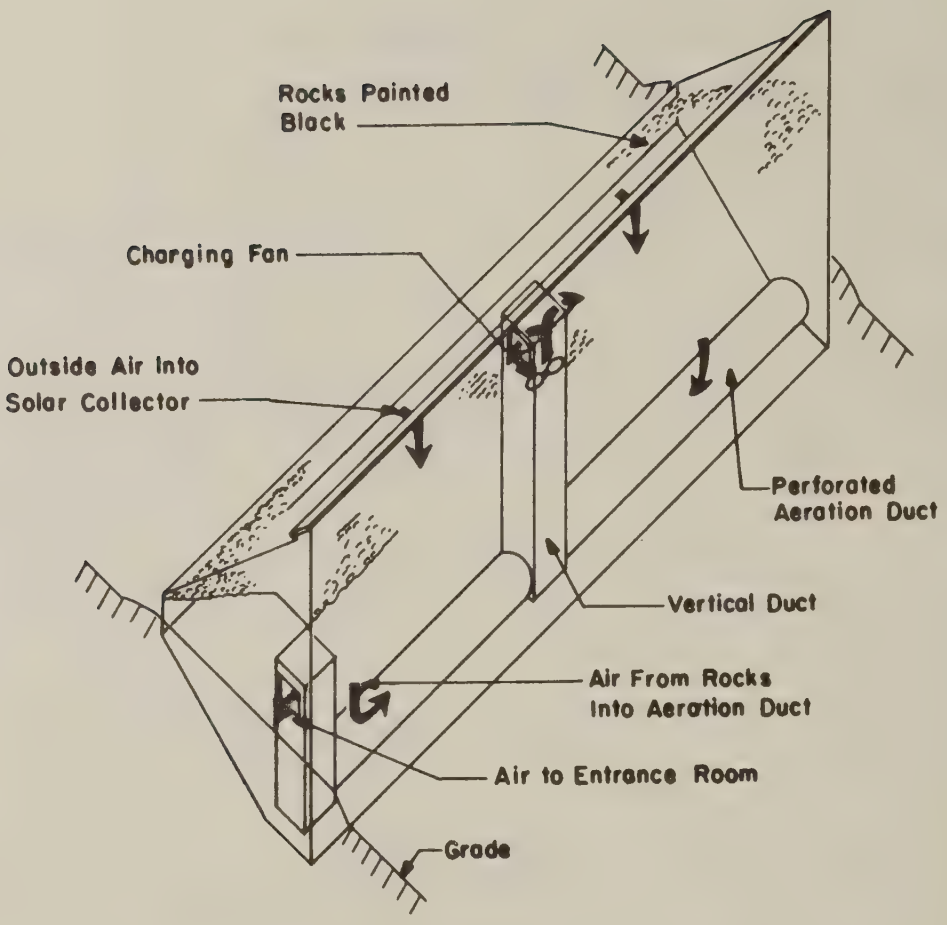


Figure 10. Plan of Borgic solar-heated nursery building (top), and cross section through solar collector showing airflow pattern (bottom).



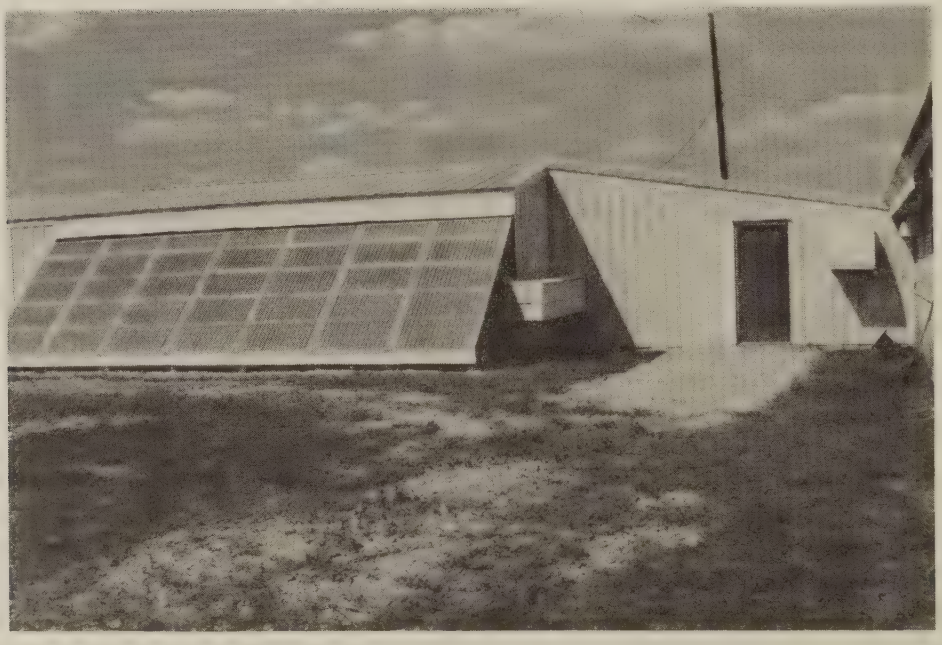


Figure 11. Borgic solar-heated nursery building: airflow pattern (top), and overall view showing lean-to collector (bottom).

points on the surface of the rock pile and the duct. The rocks are insulated from the side wall and about 2 feet into the earth by 2 inches of polystyrene insulation.

Sunlight shines through the sloped, single-layer fiberglass cover onto the rocks. The rock surface and the south-facing vertical wall are painted black to absorb sunlight. A 3,000 cfm air-circulating (charging) fan is mounted in the vertical center duct with a baffle at the top of the duct, which helps distribute the solar-heated air whenever solar energy is available to be stored. This charging fan requires a special motor designed for operation with the shaft vertical instead of horizontal. A differential thermostat with two sensors is used to control the charging fan. One sensor is located in the bottom of the aeration duct and the other under a rafter of the collector. When the sensors detect that the temperature above the rocks is higher than the temperature in the bottom of the duct, the charging fan is turned on. The fan draws air from below the rocks, through the metal perforated duct, and up the vertical duct, then discharges it above the rocks. From there it is again drawn down through the rocks. The baffle at the top of the vertical duct directs the air in both directions above the rocks at the top of the collector. As the air passes through the rocks, it gives up its heat and warms them.

To remove the heat from the rocks and use it to preheat the ventilation air, a 600 cfm fan for low-volume ventilation draws air from below the rocks and moves it into the livestock building. This small fan is sized to provide approximately the minimum, low-volume ventilation needed in the building during cold weather and runs continuously when heat is needed. For other ventilation needs, a separate, conventional ventilation system is required. Self-closing shutters on the fans prevent reverse airflows. When air is being withdrawn from the collector by the small fan, fresh air enters the collector through a 1 1/2-inch air inlet at the top of the collector. It moves down through the rocks, where it picks up heat (see air flow pattern, Figure 11).

The low-volume fan pulls heated ventilation air through a second vertical duct at one end of the aeration duct and discharges it into the entrance room. From there it is drawn through the overhead ventilation duct and distributed throughout the building. When necessary, solar-heated air entering the building can be further heated by an L.P. gas heater in the entrance room and passed into the overhead ventilation duct, which has air outlets on both sides. The low-volume ventilation fan runs continuously in cold weather, its air being preheated by the solar heating system. A high-limit thermostat shuts off the fan in mild weather when the inside temperature is as high as desired and opens a motorized shutter. At this time, the regular ventilation system takes over, bringing air in through the motorized shutter located in the wall of the entrance room.

SOLAR SYSTEM COST

The cost for the solar heating system was $1,871 for the 336 square feet of solar collector and approximately 780 cubic feet of rock heat storage, or $5.57 per square foot of collector. The system was constructed entirely with farm labor and used commonly available materials. A breakdown of costs is shown below:

Treated Lumber	$ 500
Estimated Labor at $10.00/hr	360
Rock 40 ton	260
Thermostat and Wiring	200
Fans and Shutters	175
18" Perforated Grain Drying Duct	170
Fiberglass	106
Untreated Lumber	100
	$1,871

SOLAR SYSTEM PERFORMANCE

The solar system on the Borgic's nursery building was monitored during the winters of 1980-81 and 1981-82. Since the volume of air being delivered from the solar system to the nursery building was at a constant rate, the only variables measured while monitoring were outside air temperature, temperature of air from the solar system, and the amount of available solar radiation striking the collector surface. These particular measurements were taken at 1-hour intervals as integrated values.

The periods over which monitoring occurred were February 17-23, 1981; and October 26 - November 23, 1981. From these measurements we calculated the system added 5.3 million Btu of heat energy to the ventilation air entering the nursery building during these 36 days. At certain times during this monitoring period, the temperature of the air coming from the rock storage bed was lower than the outside air temperature. This phenomenon is referred to as negative Btu and can be observed in Figure 12. The total amount of negative Btu during the 36-day monitoring period was slightly less than one million. Subtracting this amount from the 5.3 million Btu yielded a net benefit of 4.3 million Btu of heat energy. The amount of total available radiation striking the collector's surface during this period was about 14.7 million Btu. Calculating the net efficiency level gives a value of 29 percent. At this rate, the heat collected would be equal to 490 gallons of L.P. gas per heating season or 1.5 gallons per square foot of collector. A simple payback not charging for interest on the $1,871 investment would be about six heating seasons.

The only suggested change to improve efficiency would be to install a differential thermostat to the discharge fan from the heat storage and the motorized shutter which allows fresh air to enter the building so as to draw in outside air when it is warmer than air from the solar storage. Connecting the fan and shutter to the differential thermostat would solve the problem of negative Btu when air entering the building's ventilation system from the collector is cooler than the outside air. From the data collected, the effective efficiency could have been raised from 29 percent to 36 percent if the negative Btu would have been eliminated.

Another benefit of the rock storage, which is illustrated in the performance curve in Figure 12, is the uniform temperature of the ventilation air coming from the rock storage. Even though the outside air temperature varied from 28°F to about 55°F and the temperature inside the collecter varied considerably between midday and midnight, the temperature of the air coming from the rock storage only

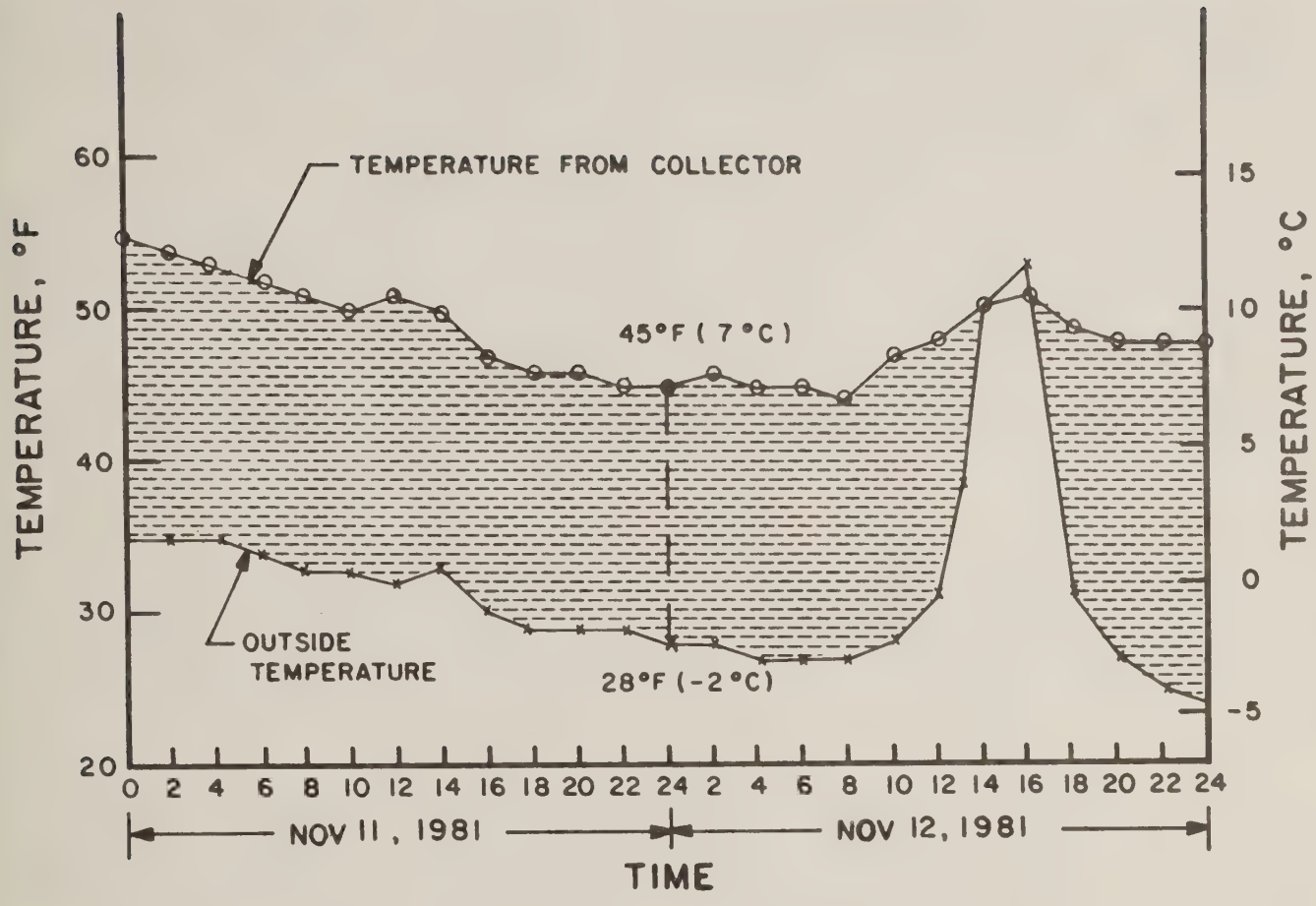


Figure 12. Performance of Borgic solar collector with rock storage, November 11 and 12, 1981.

varied a maximum of 10°F. This is a real contrast when compared to the performance of the Curry unit (Figure 14) with a solar attic, where the air temperature coming from the collector varied from a 2°F at 6:00 a.m. to 80°F at noon.

SUMMARY

At the beginning of this project, there were several objectives we hoped to achieve at the Borgic Farm. These objectives were to:

1. Provide a solar collector that would preheat the ventilation air.
2. Establish a heat storage to be used when the sun is not shining.
3. Develop a solar collector with storage that could be added to any existing or planned livestock structure.

The solar system supplied the equivalent amount of energy available from 490 gallons of L.P. gas per heating season. Extending this amount of energy out over time indicated that simple payback on the initial cost of the system would occur in six heating seasons.

One benefit of having heat storage as part of the total system was the leveling of the temperature of the ventilation air coming from the heat storage. There were periods when the outside air was warmer than the air coming from the heat storage which resulted in adding what could be considered negative Btu to the ventilation air. The negative Btu phenomenon could be overcome by installing a differential thermostat to control a motorized shutter and the fan from the heat storage. The fan from the heat storage would stop any time the outside air temperature was higher than the temperature of the air coming from the heat storage and the motorized shutter would open, allowing the warmer outside air to enter the system.

To provide more energy and deliver the ventilation air at a higher temperature, a roof or attic collector could be added. The fresh air would first pass through the roof or attic collector prior to entering the lean-to collector. Double glazing should then be installed on the lean-to collector because of the higher temperatures encountered. Also, insulation should then be used under the entire rock storage.

This new building was a modular building which was prebuilt in a factory and moved to the site. The solar collector and storage was adapted to this building just as it could be added to any existing building. Mr. Borgic and his sons built this collector themselves from plans now available from the Agricultural Engineering Department, University of Illinois, Urbana, Illinois 61801.

CONCLUSIONS

This system seems to be economically feasible at today's energy costs, particularly when it can be constructed with on-farm labor and locally available materials, as was done in this case.

PERFORMANCE DATA

Solar System Efficiency Level: 29%

Collector Size: 336 ft^2 Solar System Cost: $1,871

Assumptions

1. Temperature of ventilation air to farrowing room needed to achieve comfort zone -- 75°F
2. Heating season (HS) is September through May
3. L.P. gas as an average conventional fuel source provides 73,600 Btu/gal

4. On a south-facing 45° sloped surface, approximately 370,000 Btu/ft^2 are available from September through May

5. 1 gal of L.P. gas costs $0.60

Payback Calculation

$$\frac{370{,}000 \text{ Btu}}{ft^2\text{-HS}} \times .29 \times 336 \text{ } ft^2 \times \frac{1 \text{ gal L.P.}}{73{,}600 \text{ Btu}} = 490 \text{ gal L.P./HS}$$

$$\frac{490 \text{ gal L.P.}}{\text{HS}} \times \frac{\$0.60}{\text{gal L.P.}} = \$294.00/\text{HS}$$

$$\frac{\$1{,}871}{\$294/\text{HS}} = 6.4 \text{ heating seasons until payback}$$

Curry Farm

Henry County, Illinois

GENERAL DESCRIPTION

The hog and grain farm of Charles Curry is located in northwestern Illinois in Henry County. The swine production system has several buildings capable of producing approximately 4,000 hogs each year. The solar building being studied is a 47-by-104-foot farrowing and nursery building with five farrowing rooms and two nursery rooms, divided by a working aisle (see Figure 13).

The solar roof is sloped 50 degrees from horizontal and faces south. It measures 20 by 104 feet and is covered with clear, greenhouse grade fiberglass. The lower portion has been extended below the ceiling line to provide as much solar collection surface as possible. This extended roof area functions as a covered plate collector preheating the air before it enters the solar attic.

Air, warmed in the collector, is used to ventilate the building during the winter and to dry grain during the fall. Supplemental hot water for in-floor heating is provided by a boiler fired by gas.

The building was originally constructed in 1978 with the entire solar attic open. In 1980, when this project was started, the building was modified to increase the efficiency of the solar attic. A lengthwise vertical partition was added to reduce the attic volume (see cross section, Figure 13). The partition of black-painted polyurethane insulation boards extends from the attic floor up to the north roof slope. The black surface acts as a solar absorber during the winter when the sun is low in the sky. Conversely, during the summer when the sun is high in the sky, the rays do not make contact with the black surface, which reduces heat buildup in the attic. A small section of north sloping roof over the solar attic has batt insulation placed between the roof purlins.

GOALS

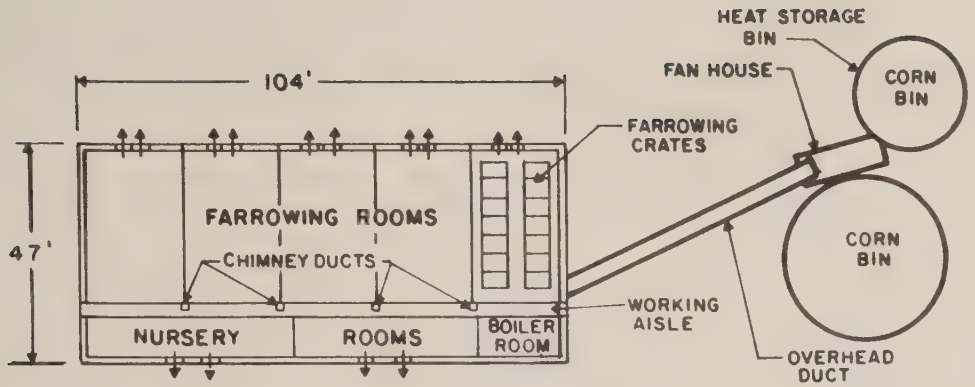
The major goals governing the design and construction of this system are:

1. To provide a solar collector which preheats the winter ventilation air for the farrowing-nursery building.

2. To provide solar heat for low temperature grain drying in the two nearby grain bins.

3. To modify a full attic collector and evaluate the performance of reducing the volume of the attic and partitioning off the north roof with insulated material.

4. To evaluate the use of one grain bin for storing heat during cold weather.



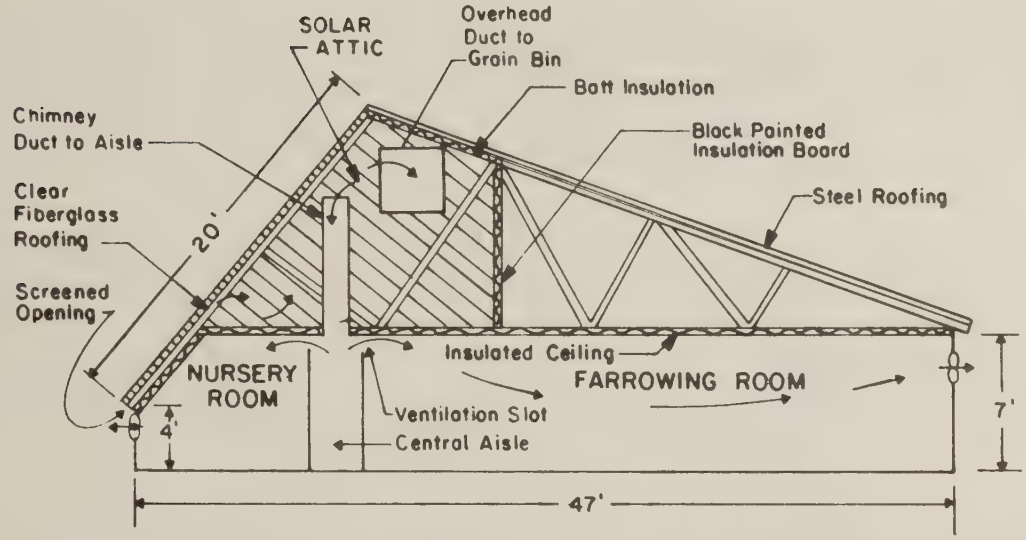




Figure 13. Plan of Curry farrowing-nursery building (top), cross section of building showing modified solar attic (middle), and overall view of unit (bottom).

SOLAR SYSTEM DESCRIPTION

Air enters the collector through a screened opening below the eaves on the south side of the roof (see Figure 13).

Movement of air through the solar attic is activated by exhaust fans on the outside walls of the farrowing and nursery rooms. When the fans are running, a negative pressure is created in the building, causing solar-heated air to be drawn from the peak of the attic, where it is warmest, down the chimney ducts into the central aisle. The air is then pulled from the central aisle across the farrowing and nursery rooms through slots at the top of the walls. These slots are equipped with plastic anti-back-draft curtains that allow fresh air to flow into the rooms but prevent a back draft of air out of the rooms. The curtains reduce the possibility of moisture-laden air rising into the attic where it could cause severe condensation problems.

In hot weather, the chimney ducts are closed off and fresh air for ventilation enters through hooded openings located over the doors at each end of the central aisle. A thermostatically controlled exhaust fan is mounted in the east attic wall. This fan runs when attic temperatures are above 180°F, which helps to maintain a reasonable temperature in the attic.

Grain Drying: The grain drying system is comprised of two bins each equipped with a fan and stirring device. The smaller 8,000-bushel bin is equipped with a 10-horsepower axial fan for drying; the larger 17,000-bushel bin, with a 20-horsepower centrifugal drying fan. These fans pull heated air from the solar attic through a 4-by-4-foot overhead duct to the fan house, from where it is forced up through the grain.

Experimental Heat Storage: Water or a rock mass is the normal medium used to store solar energy. In this solar heating system, however, an effort has been made to store excess heat in the shelled corn being stored in the smaller of the two grain bins. Excess heat from the solar attic is stored in the corn during the day and returned to the building at night. The heated air is moved to and from the grain bin through the same overhead duct used for grain drying. The duct is insulated with 1 inch of expanded polystyrene insulation to conserve as much heat as possible. A thermostatically controlled 3,200 cfm fan mounted in the overhead duct moves warmed air (excess heat) from the solar attic during the middle of the day and forces it up through the stored grain. During the night, another 1,200 cfm fan controlled by a timer pulls air down through the grain and thus returns stored heat to the hog building's ventilation system. This fan delivers only enough warm air to the central aisle to meet the pigs' winter minimum ventilation air needs.

SOLAR SYSTEM COST

The cost of the solar system and modifications made for storing heat was $4,766 or $2.29 per square foot of the solar collector surface. A breakdown of the costs is as follows:

Materials Used to Modify Attic	$ 900
Materials Used to Modify Duct	1,380
Fans, Shutters, and Motors for Heat Storage	382
Fiberglass Cost minus Metal Roofing Cost (2,080 ft^2)	104
Estimated Labor	2,000
	$4,766

SOLAR SYSTEM PERFORMANCE

Air temperatures, ventilation air flow, and solar radiation levels were measured during the periods of March 20-26, 1980; April 2-9, 1981; and March 5-April 14, 1982. In addition, solar grain drying information was obtained during the grain drying season of 1980 from September 10 through October 12.

Figure 14 shows a performance curve for heating the ventilation air for a 2-day period during winter in 1980. During midday the ventilation air temperature was raised 50° to 60°F above the outside air. From 5:00 p.m. to

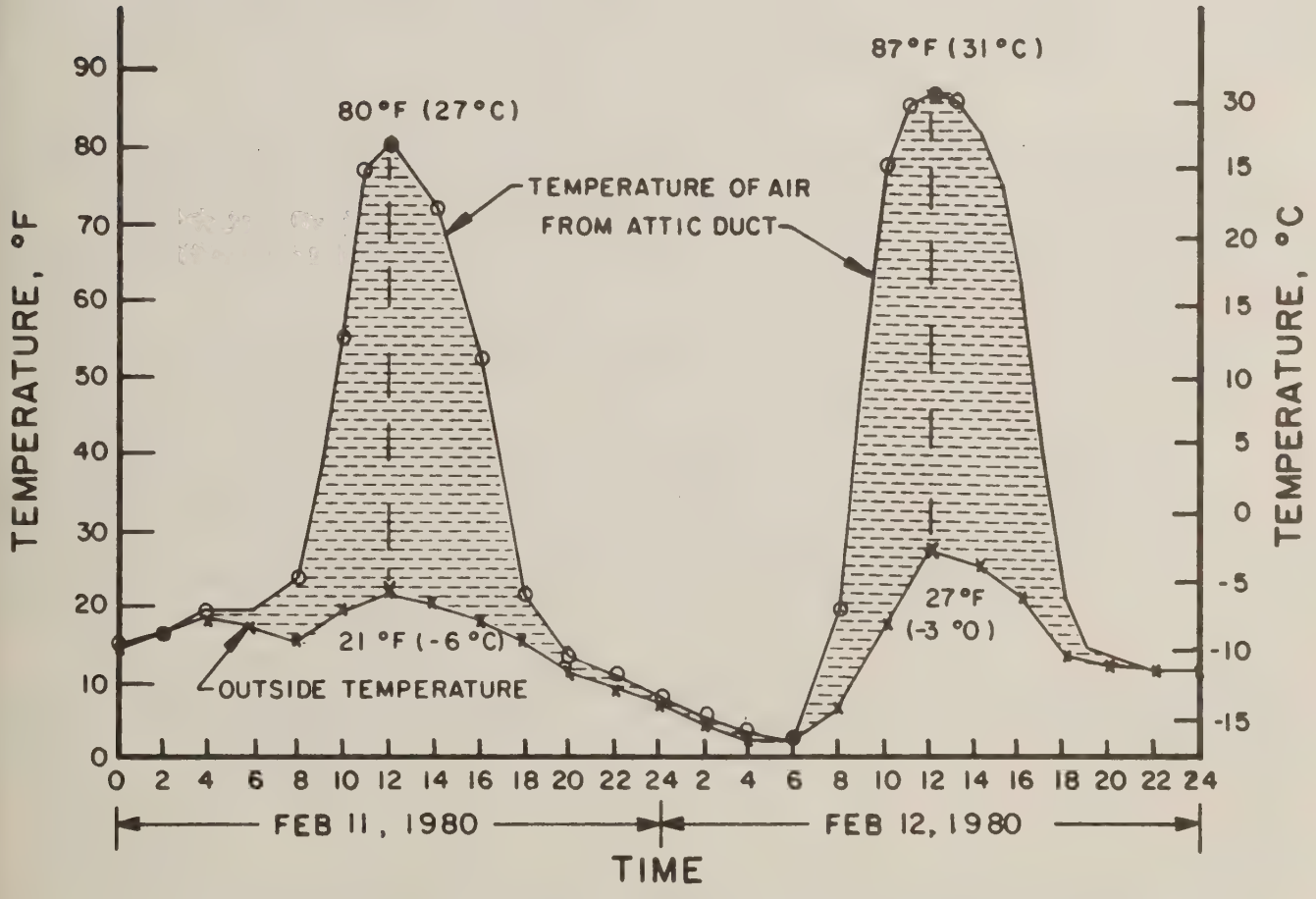


Figure 14. Performance of Curry modified solar attic, February 11 and 12, 1980. (The heat storage system was not operating.)

8:00 a.m. there is essentially no heating of the ventilation air by the solar system. One might question if all the solar energy collected at midday was useful when calculating the efficiency of the system.

From the measurements made while using the solar system to preheat ventilation air, we calculated that the solar system delivered 10.5 million Btu of heat energy to the ventilation air during these 56 days. The total amount of available solar radiation striking the collector's surface was 66.2 million Btu. This represented an efficiency level of slightly less than 16 percent. At this rate, the heat delivered by the solar system for heating the ventilation air would replace 1,017 gallons of L.P. gas per heating season. A simple payback, not charging for interest on the $4,766 investment and not considering any benefit for drying, would be about 7.8 heating seasons. Since the total cost of the solar system includes the drying duct, the heat storage fans and controls, and the livestock ventilation preheat system, all of these factors were included when figuring payback.

The heat storage fans and controls which are included in the total cost do not seem to justify the added initial cost or the added cost of operation in terms of amount of heat recaptured. The only monitoring period during which the heat storage was in operation was April 2-9, 1981. During this 7-day period only 19 percent or 468,000 Btu of the heat transfered to the heat storage were returned to the building. It must be kept in mind that the heat is added to the storage only when the solar attic temperature exceeds 75°F. This occurs infrequently during the winter.

The other factor which influences total system cost is the grain drying portion of the solar system. Since this system has been designed to provide adequate area for increased airflow, the system was used to preheat the air used for grain drying. With the increased air flow through the collector and the resulting improvement in system efficiency, the time needed to pay off the added cost of the solar system is reduced.

Measurements were taken during the grain drying season of 1980. From September 10 to October 12, 33,000 bushels of corn that initially ranged from 29 to 19 percent moisture were dried in batches in the two bins connected to the solar collector. With stirring devices in both bins, the corn was dried to a moisture content of 16 percent. Except for 20 gallons of L.P. gas that was used in a burner when time became a factor during harvest, all of the heat used to dry dry the grain was supplied by the solar system. Comparing the cost of L.P. gas to dry this amount of corn in the conventional manner and the cost of using solar energy, shows a savings when using solar energy of $2,280 per season.

Considering the benefits derived by using the solar system for both grain drying and preheating ventilation air the time required to pay off the $4,766 cost of the solar system is reduced to 1.6 seasons.

SUMMARY

When the Currys first built this solar heated farrowing nursery building in 1978, their main goals were to:

1. Provide a solar collector which preheats the winter ventilation air for the farrowing-nursery building.

2. Provide solar heat for low temperature grain drying in two nearby grain bins.

Once they become a cooperator in the solar livestock demonstration project, additional goals were to:

3. Modify the full attic collector and evaluate the performance of the solar system.

4. Evaluate the use of one grain bin as a heat storage during the winter months.

According to calculations made from the measurements taken while using the modified solar attic to preheat the ventilation air, the solar system would supply the equivalent amount of energy available in 1,017 gallons of L.P. gas per heating season. Extending this savings of energy over time indicates simple payback on the initial cost of the system would occur in about eight heating seasons.

Measurements taken during the grain drying season show that the use of solar energy for grain drying also saved $2,280 per drying season. Taking into account the benefits from both grain drying and ventilation air preheat, the time required to pay off the $4,777 cost is reduced to 1.6 years.

The modification made to the solar attic was to partition the colder north attic space from the south-facing solar portion of the attic. This was accomplished by installing black painted polyurethane insulation boards, which also acted as the solar absorber, from the floor of the attic to the roof. Batt insulation was also installed betwen the purlins of the small amount of north sloping roof that was in the solar attic. The size of the attic was reduced but there was still sufficient area to satisfy the higher airflow required during drying.

The poor performance of the heat storage and retrieval system is not explained. It may have been due to the lack of insulation in the storage bin and transition ducts and also to air leaks in the connections from the overhead duct to the storage bin. Time and instrumentation were not available to analyze the problem and make changes. It would seem possible to return much more than 19 percent of the heat from storage.

Overdrying of the corn at the bottom of the bin, which was feared, was not severe. Moisture content at the bottom of the bin was about 13 percent, causing no problem if being fed to livestock.

CONCLUSIONS

From the performance of this attic solar system after the modification was made, we strongly feel the performance of any east-west attic solar collector could be improved if the attic were partitioned off and only the south side used.

This would not be possible if the building were oriented north and south because fiberglass roofing would be required on both the east and the west sides of the roof. The use of the system for both ventilation preheat and crop drying made it an excellent investment.

PERFORMANCE DATA

Solar System Efficiency Level: 16%

Collector Size: 2,080 ft^2 Solar System Cost: $4,766

Assumptions

1. Temperature of ventilation air to farrowing room needed to achieve comfort zone -- 68°F
2. Heating season (HS) is November through April
3. L.P. gas as an average conventional fuel source provides 73,600 Btu/gal
4. Although collector is sloped at 50°, calculations are based on a south-facing 45° sloped surface
5. On a south-facing 45° sloped surface, approximately 225,000 Btu/ft^2 are available from November through April
6. The cost for conventional drying with fuel and electricity is $0.10 per bushel
7. The cost of solar drying is the cost of running 2 fans (10 and 20 hp), approximately 25 kWh
8. It is known that 33,000 bushels of corn was dried from 24 to 16 percent moisture by this solar system between the days of September 10 and October 12.
9. Electricity as an energy source provides 3,413 Btu/kWh at $0.05/kWh
10. 1 gal of L.P. gas costs $0.60

Payback Calculation

Ventilation

$$\frac{225{,}000 \text{ Btu}}{ft^2\text{-HS}} \times .16 \times 2{,}080 \text{ } ft^2 \times \frac{1 \text{ gal L.P.}}{73{,}600 \text{ Btu}} = 1{,}017 \text{ gal L.P./HS}$$

$$\frac{1{,}017 \text{ gal L.P.}}{\text{HS}} \times \frac{\$0.60}{\text{gal L.P.}} = \$610.20/\text{HS}$$

Conventional Drying

33,000 bu x $0.10/bu = $3,300

Solar Drying

25 kWh x 34 days x 24 hr/day x $0.05/kWh = $1,020

Difference between drying methods

$3,300 - $1,020 = $2,280

Payback

$$\frac{\$4{,}766}{\$610.20 + \$2{,}280} = 1.6 \text{ seasons until payback}$$

Korsmeyer Farm

Cass County, Illinois

GENERAL DESCRIPTION

The hog production unit of Willard Korsmeyer is located along the Illinois River in Cass County in west-central Illinois. His farrow-to-finish production unit is capable of producing approximately 8,000 hogs per year. The entire hog production system was planned for utilizing solar energy to heat the building (Figure 15). His 48-by-575-foot farrow-nursery-finishing building, built in 1977-78, has a solar collector on the south wall and a solar attic over the 150-foot farrow-nursery section.

The 48-by-96-foot confinement breeding building studied in this demonstration project was constructed in 1979 (Figure 16). It is used for housing the boars, providing space for breeding the sows, and holding the sows a short period before and after breeding. Clear fiberglass roofing on the south side of the 4/12 sloped roof forms a covered plate collector. Urethane insulation board, 0.8 inch thick, with the surface painted black, forms the absorber plate. A 1 1/2-inch air space has been left between the fiberglass roof and the insulation board. Two parallel tunnels, each about 2 by 4 feet, run under the floor for the entire length of the building. The tunnels are made up of about 40 tons of concrete blocks.

Heated air collected and stored in this breeding building is also ducted into the hallway of the adjoining building to be used to help heat the farrowing and nursery sections.

GOALS

The following objectives governed the design and construction of this solar system:

1. To build a solar collector and heat storage that would provide some heat for the breeding building.

2. To provide additional heated air for the farrowing and nursery sections of the adjoining building.

SOLAR SYSTEM DESCRIPTION

At both ends of the breeding building, ducts connect the covered plate solar collector on the south side of the roof with the concrete block heat storage channels. Air is circulated through the roof collector, down to the heat storage channels, through the channels under the concrete floor, and back up to the roof collector (see Figure 17). A separate 1,500 cfm fan moves the air through each heat storage channel from the roof collector. A separate duct with a 600 cfm fan

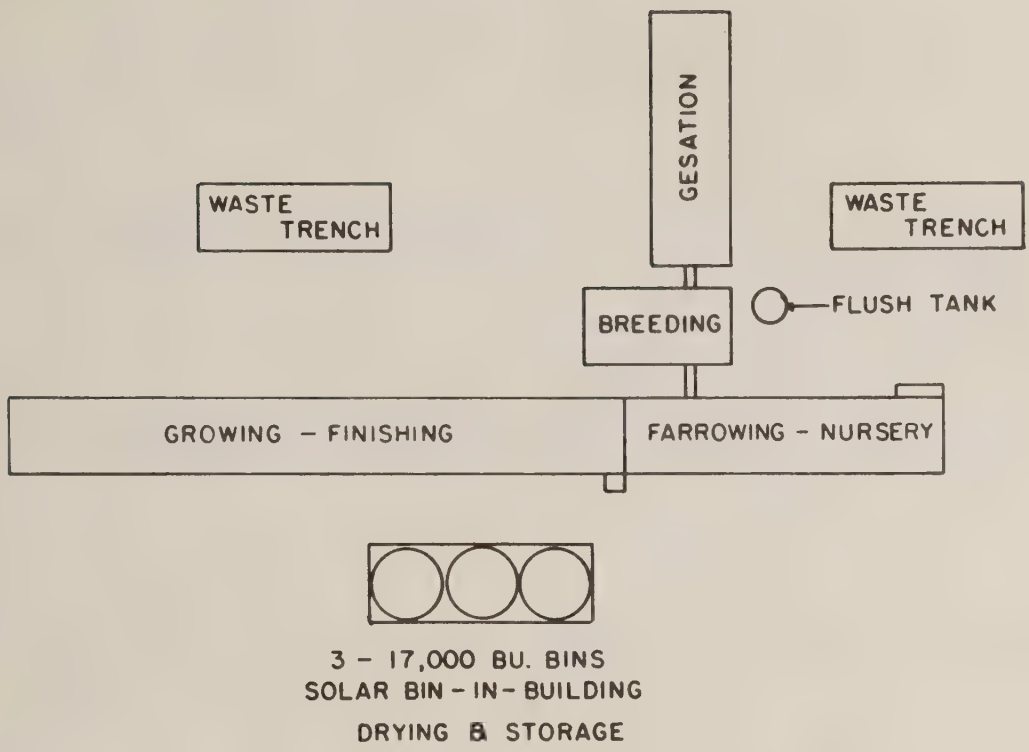




Figure 15. Overall layout of Korsmeyer pig production system (top), and view of two buildings (bottom): breeding building (right), and growing-finishing unit (left).

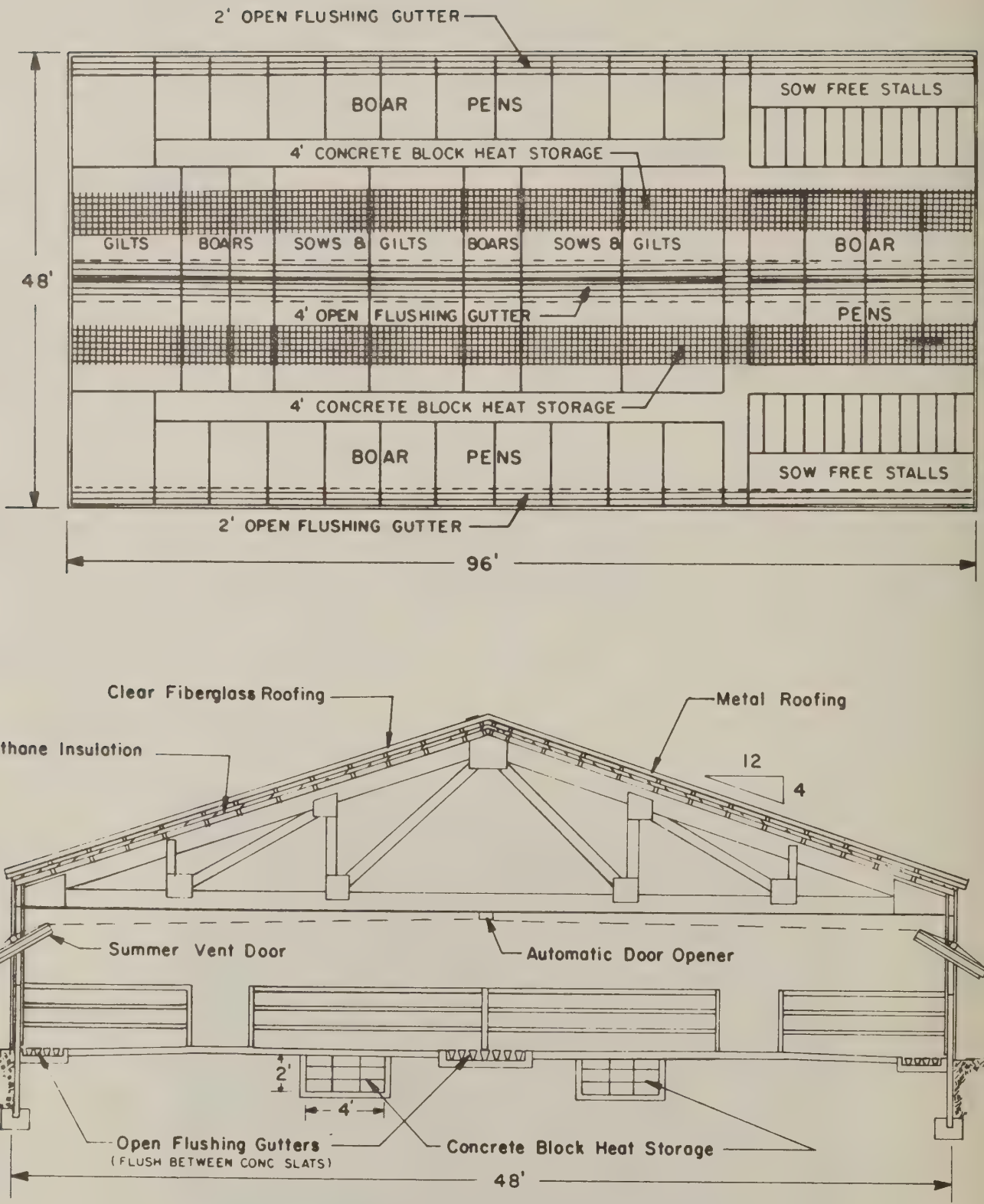


Figure 16. Plan (top) and cross section (bottom) of Korsmeyer solar-heated breeding building. Both views show location of concrete block heat storage ducts and open flushing gutters.

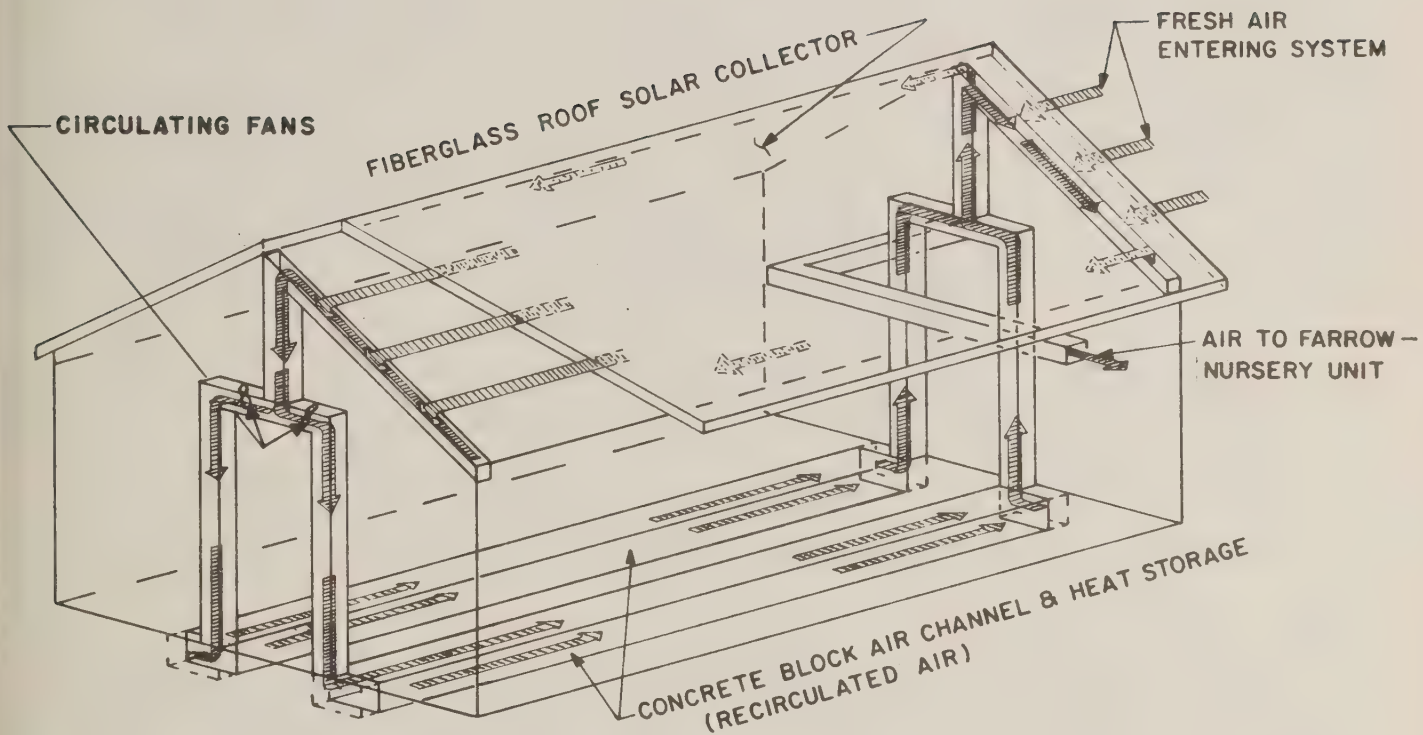


Figure 17. Airflow pattern through Korsmeyer solar-heated breeding building.

also takes air from this recirculating duct and delivers it to the hallway of the nearby farrowing-nursery unit to help warm the winter ventilation air. Fresh air needed to replace the air delivered to the nearby building enters the collector at the east edge of the roof.

The heat stored in the concrete block heat storage is utilized by two methods. In the breeding building, this stored heat radiates up from the concrete blocks through the concrete floor, providing a warmed floor area in most sow pens. This is the only solar heat delivered to the breeding area. Heated air is also withdrawn from the recirculating duct and delivered to the farrowing-nursery units in the nearby building.

SOLAR SYSTEM COST

The cost of the solar portion of this system was approximately $5,000 for the 2,450 square feet of collector. This breaks down to a cost of $2.04 per square foot. A breakdown of the costs is shown below:

Materials	$2,538
Concrete Blocks (heat storage)	650
Fiberglass Cost Minus Metal Roofing Cost (2,482 ft^2)	121
Estimated Labor	1,691
	$5,000

SOLAR SYSTEM PERFORMANCE

Monitoring began at the breeding building during the winter of 1980-81. Since the volume of air being delivered from the concrete block heat storage to the farrowing-nursery area was at a constant rate, the only variables that were measured were time of operation of discharge fan, outside temperature, temperature of air moving via discharge fan from concrete block heat storage to farrowing-nursery area, and the amounts of available solar radiation striking the solar roof. Except for time of operation of the discharge fan, which was controlled and recorded by the herdsman, all of the measurements were taken as integrated values at one-hour intervals.

The periods over which monitoring occurred were February 24 - March 2, 1981; March 24, 1982, and March 29 - April 2, 1982. The trial in 1982 is viewed as distinctly different from the 1981 trial. During the first trial, in 1981, the herdsman operated the discharge fan continuously while during the 1982 trial the herdsman elected to exercise his option of manually controlling the discharge fan which moved air from the concrete block heat storage to the farrowing-nursery area.

Figure 18 shows a performance curve of the air coming from the heat storage ducts of the breeding building for a 2-day period during the winter of 1981. Again, it is easy to see how air coming from a heat storage does not vary as much in temperature as does air coming directly from a collector. The maximum heating from the heat storage occurs during the nonsolar hours.

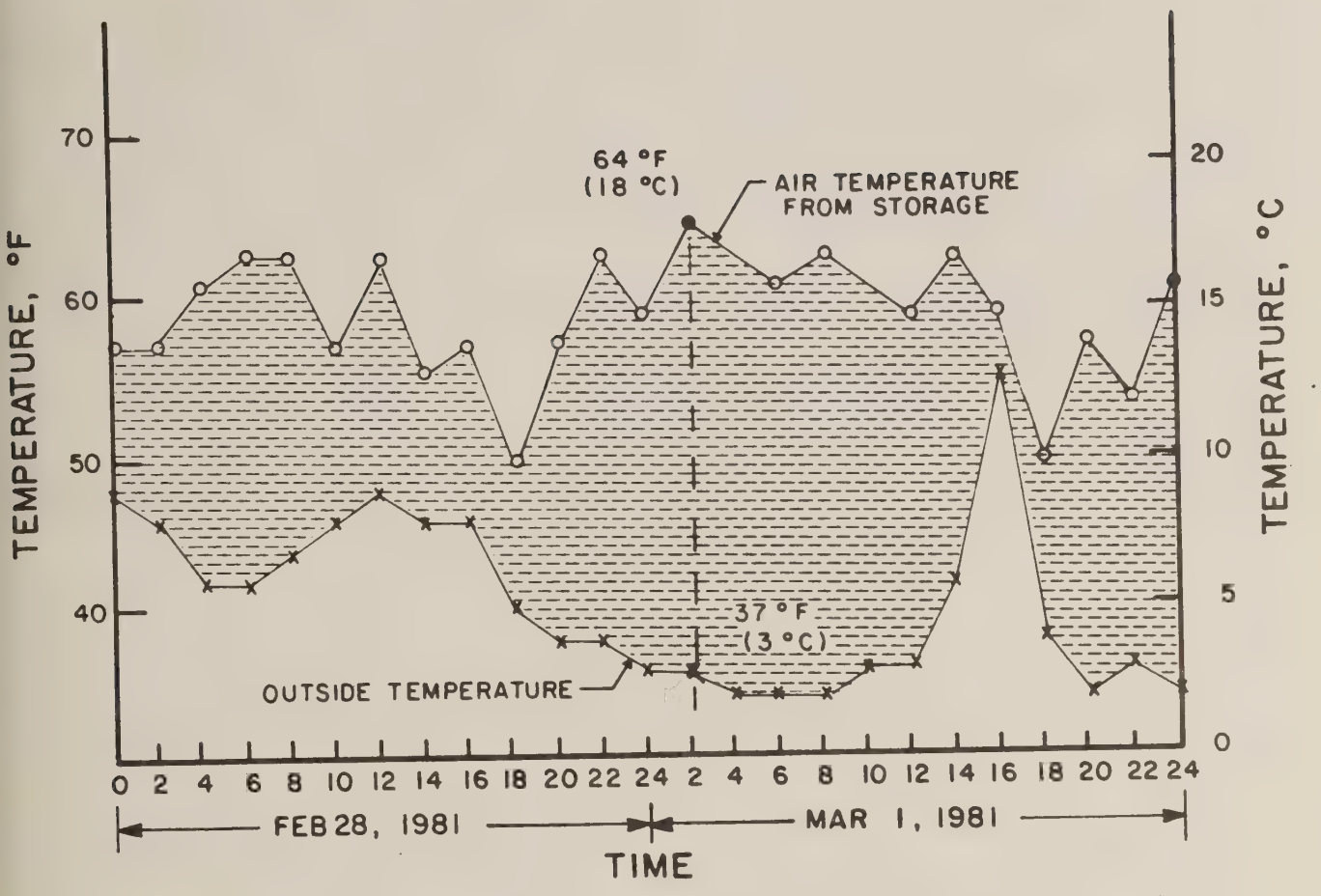


Figure 18. Temperature of air being directed from Korsmeyer solar-heated breeding building to nearby farrowing-nursery unit, February 28 and March 1, 1981.

From our measurements, we calculated that during the first trial, covering seven days in 1981, the system added slightly less than 1.6 million Btu of heat energy to the duct supplying supplemental ventilation air to the farrowing-nursery area. The total amount of available solar radiation striking the solar roof during this period was around 19 million Btu. This represents an overall efficiency of 8 percent for the amount of heat transferred to the farrowing-nursery building. During the second trial, when the herdsman controlled the discharge fan, the system added slightly more than half a million Btu of heat energy to the ventilation air entering the farrowing-nursery area. The total amount of available solar radiation striking the solar roof during these periods was around 25 million Btu. The overall efficiency fell to only 2 percent for the amount of collected heat made available to the neighboring building.

Certain factors, however, affect the reliability of both of the trial performance levels. First, the building which houses the farrowing-nursery area is equipped with a solar attic that is used to preheat the ventilation air going to the farrowing-nursery area during the day. It is necessary to compare the

temperature of the ventilation air coming from the solar attic and the temperature of the ventilation air coming from the concrete block heat storage so as to bring in air from the heat storage only when it is warmer than the air coming from the solar attic. Since neither continuous operation of the heat storage discharge fan nor allowing the operator to estimate the timing of fan operations seems to be an acceptable alternative, installation of a differential thermostat which automatically compares these temperatures appears to be the best solution to this control problem. The differential thermostat is economically feasible since it has the potential of increasing the efficiency by a factor of four, from 2 percent to 8 percent. Correspondingly, it can reduce the time required to pay off the total cost of the system to one-fourth.

Another factor, unmeasured yet considered by the producer to be beneficial, was the amount of heat radiating up from the concrete block heat storage through the concrete floor into the breeding building. Because dry floors are desirable in a building used for breeding, the producer felt the radiant heat from the heat storage helped to maintain dry floors in the breeding building.

SUMMARY

When this project began, the producer wanted a new breeding building near his existing solar-heated farrowing-nursery building. He decided the new building should also utilize solar energy. His goals were to:

1. Provide radiant heating to the breeding building by installing a concrete block heat storage system under the floor. This radiant heating would also help maintain dry floors.

2. Provide additional heated air for the farrowing and nursery sections in the adjoining building by removing this heat from the concrete block heat storage.

The only objective that could be measured with the instruments used in this project was the amount of additional preheated air delivered to the adjoining building. This amount of energy ranged from 2 to 8 percent of the total available solar energy striking the building's solar collector surface. The variation in performance is probably due to the method of controlling the fan delivering heated air. During the trial when the level of performance was 2 percent, the herdsman manually controlled the fan. When the fan was left on continuously, the performance improved to 8 percent of the total available solar energy.

Certain factors, however, affect the reliability of both of the trial performance levels. First, the building that houses the farrowing-nursery area is equipped with a solar attic that preheats the ventilation air going to the farrowing-nursery area during the day. It is necessary to be able to compare the temperatures of the ventilation air coming from the solar attic and of the air coming from the concrete block heat storage, because air from the heat storage should be delivered to the farrowing-nursery area only when it is warmer than the air coming from the solar attic. Since neither continuous operation of the heat storage discharge fan nor allowing the operator to estimate the timing of fan operation seems to be an acceptable alternative, installation of a differential

thermostat which automatically compares these temperatures appears to be the best solution to this control problem. The differential thermostat is economically feasible because it has the potential of increasing the efficiency by a factor of four, from 2 percent to 8 percent. Correspondingly, it can reduce the time required to pay off the total cost of the system to one-fourth. Assuming the 8 percent efficiency level would be maintained throughout the winter, the resulting savings in heat would be equivalent to the energy available from 14,230 kWh, for a 7-year payback period.

The other factor, unmeasured, was the amount of heat radiating up from the concrete block heat storage through the concrete floor into the breeding building. The producer felt the radiant heat helped to dry the floor, which is particularly beneficial in a building used for breeding.

CONCLUSIONS

It is difficult to fully evaluate the economic feasibility of this system because of the highly variable results of continuously or manually directing heat to the farrow-nursery building and also because of inability to measure the heat radiating up through the heat storage.

PERFORMANCE DATA

Solar System Efficiency Level: 2%*

Collector Size: 2,428 ft^2 Solar System Cost: $5,000

Assumptions

1. Temperature of ventilation air to farrowing room needed to achieve comfort zone -- 68°F
2. Heating season (HS) is October through April
3. Calculations are based on electrical energy since it is utilized as the energy source for heating by this producer.
4. Electricity as an energy source provides 3,413 Btu per kWh
5. 1 kWh cost is $0.05
6. On a south-facing 4/12 sloped surface, approximately 250,000 Btu/ft^2 are available from October through April

*This solar system efficiency level was only for the very small amount of heat transferred over to the nearby farrowing-nursery unit.

Payback Calculation

$$\frac{250{,}000 \text{ Btu}}{\text{ft}^2\text{-HS}} \times .02 \times 2{,}428 \text{ ft}^2 \times \frac{1 \text{ kWh}}{3{,}413 \text{ Btu}} = 3{,}557 \text{ kWh/HS}$$

$$\frac{3{,}557 \text{ kWh}}{\text{HS}} \times \$0.05 = \$177.85/\text{HS}$$

$$\frac{\$5{,}000}{\$177.85/\text{HS}} = 28 \text{ heating seasons until payback}$$

Marley Farm

Montgomery County, Illinois

GENERAL DESCRIPTION

The Jerry Marley farm is located in central Illinois in Montgomery County. His 48-by-280-foot production line unit has five farrowing rooms, five nursery rooms, and a breeding and gestation area as shown in Figure 19. The south side of the roof is constructed at 45 degrees to the horizontal to provide an optimum roof angle for collecting the winter solar energy. The west 108 feet of the south roof has a water solar collector and the remaining 172 feet has a solar attic with clear fiberglass roofing.

The goal of this project was to extensively monitor the solar water heating panels on the west end of the south roof. The solar attic was not monitored and, therefore, will not be described here.

The commercial water solar collector is composed of thirty 4-by-10-foot solar hot water panels totaling 1,200 square feet of absorber. The solar hot water panels are made up of 1/2-inch copper pipes with a copper absorber plate soldered to each pipe making a 4.6-inch wide surface. The absorber plates are painted with black chrome selective surface paint. Each 4-by-10-foot panel has ten runs of 1/2-inch copper pipe.

The solar hot water panels are mounted in the roof with a 1-inch polyurethane insulation board under the panel. Clear corrugated fiberglass roofing with a protective coating is used as the outside roof surface.

The solar system has a well insulated 6,000-gallon storage tank which serves as the heat storage. The hot water solar system is used with a back-up boiler and an in-floor heating system.

GOALS

The following objectives governed the design and construction of this solar system:

1. To provide a hot water solar collector that would furnish some solar energy for the in-floor radiant heating system, thus reducing the costs for other fuel.

2. To provide heat storage capability for use during nonsolar periods.

3. To provide an additional attic collector to preheat the ventilation air for farrowing and nursery rooms.

4. To provide controls so minimum management is required during operation.

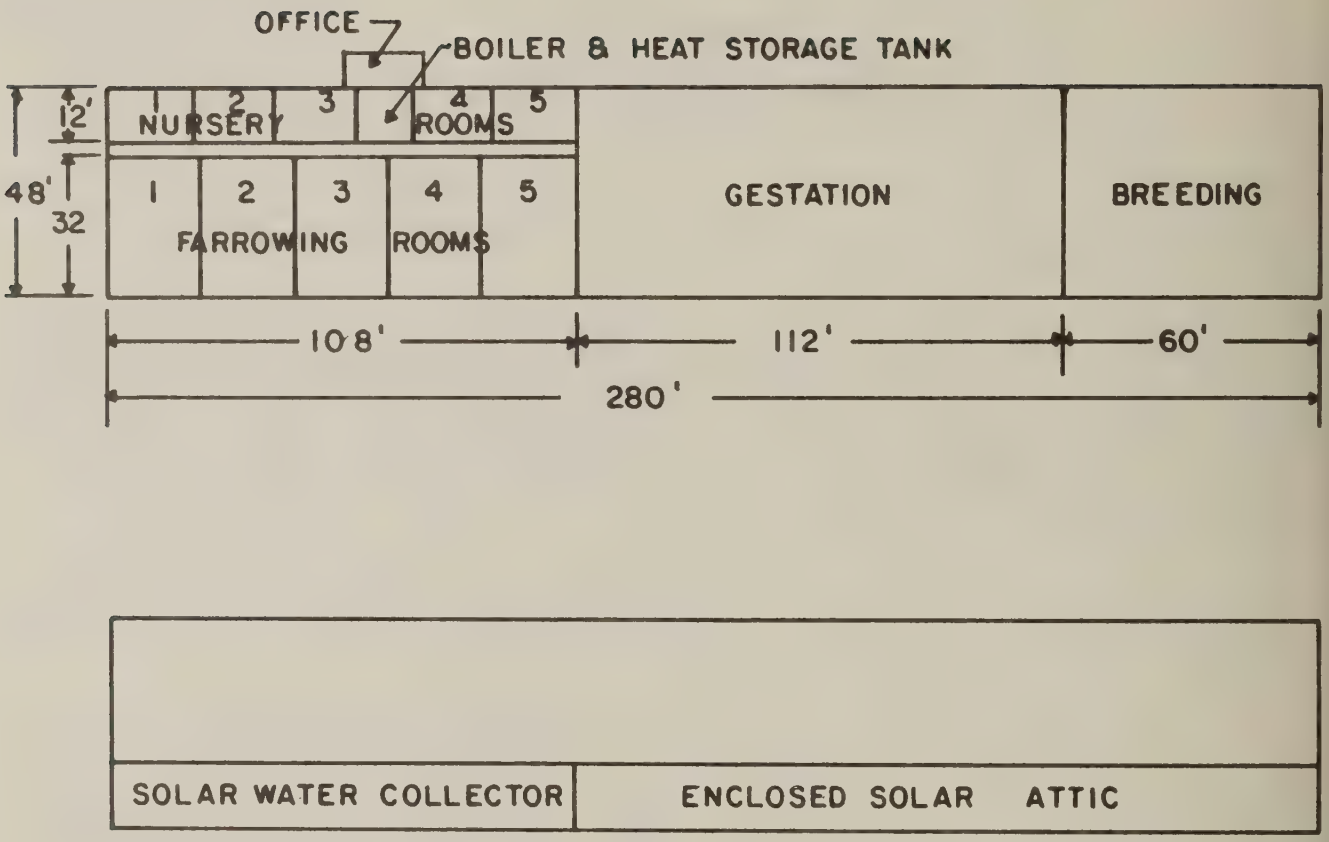




Figure 19. Marley solar-heated swine unit: plan showing arrangement (top), top view showing location of solar collectors (middle), and overall view (bottom).

SOLAR SYSTEM DESCRIPTION

The solar hot water system (Figure 20) is controlled by a differential thermostat. The pump that delivers water from the storage tank to the solar panels is activated whenever the thermostat senses the temperature of the collector is 10°F higher than the temperature of the water at the bottom of the storage tank. When the temperature of the solar panels falls below this temperature, the pump turns off. The solar panels are mounted at an angle so when the pump isn't running, a solenoid valve opens which allows the water in the solar panels to drain back into the storage tank. These panels are drained to avoid the problems of water freezing and causing the pipes to burst in cold weather. Because of the draindown feature, a self priming pump is required.

Water for the hot water in-floor radiant heating system in the farrowing and nursery rooms can either be drawn from the top of the storage tank through the boiler or recycled from the in-floor heat return line through the boiler. A second differential thermostat detects the water temperatures in the return line and at the top of the storage tank and directs the warmest water through the boiler. Thermostat controlled zone valves accomplish this task automatically.

SOLAR SYSTEM COST

The cost of the solar water heating and storage portion of the building is $16,420. This works out to a square foot cost of $9.50 for the total collector area. A breakdown of costs is shown below:

Absorber, Insulation, Plumbing	$12,000.00
Estimated Labor	2,200.00
Flat Fiberglass	1,210.00
Concrete	200.00
Miscellaneous	723.60
Fiberglass Cost minus Metal Roofing Cost (1,728 sq ft)	86.40
	$16,420.00

SOLAR SYSTEM PERFORMANCE

During the installation of the hot water collector, the 4-by-10-foot panels were installed horizontally instead of in the usual vertical orientation. Even though the panels were tilted to allow for draindown when the pump wasn't running, the 10-foot long, 1/2-inch copper tubing sagged, allowing water to remain in the collector causing the pipes to burst because of freezing.

The original panels were anchored only at the ends and were tilted only 2 inches in the 10 feet of length. The collector panels were not repaired until the spring of 1982, when they were individually removed from the roof and tilted 8 inches in the 10-foot run. Also, each 1/2-inch tube was supported at the center as well as at each end.

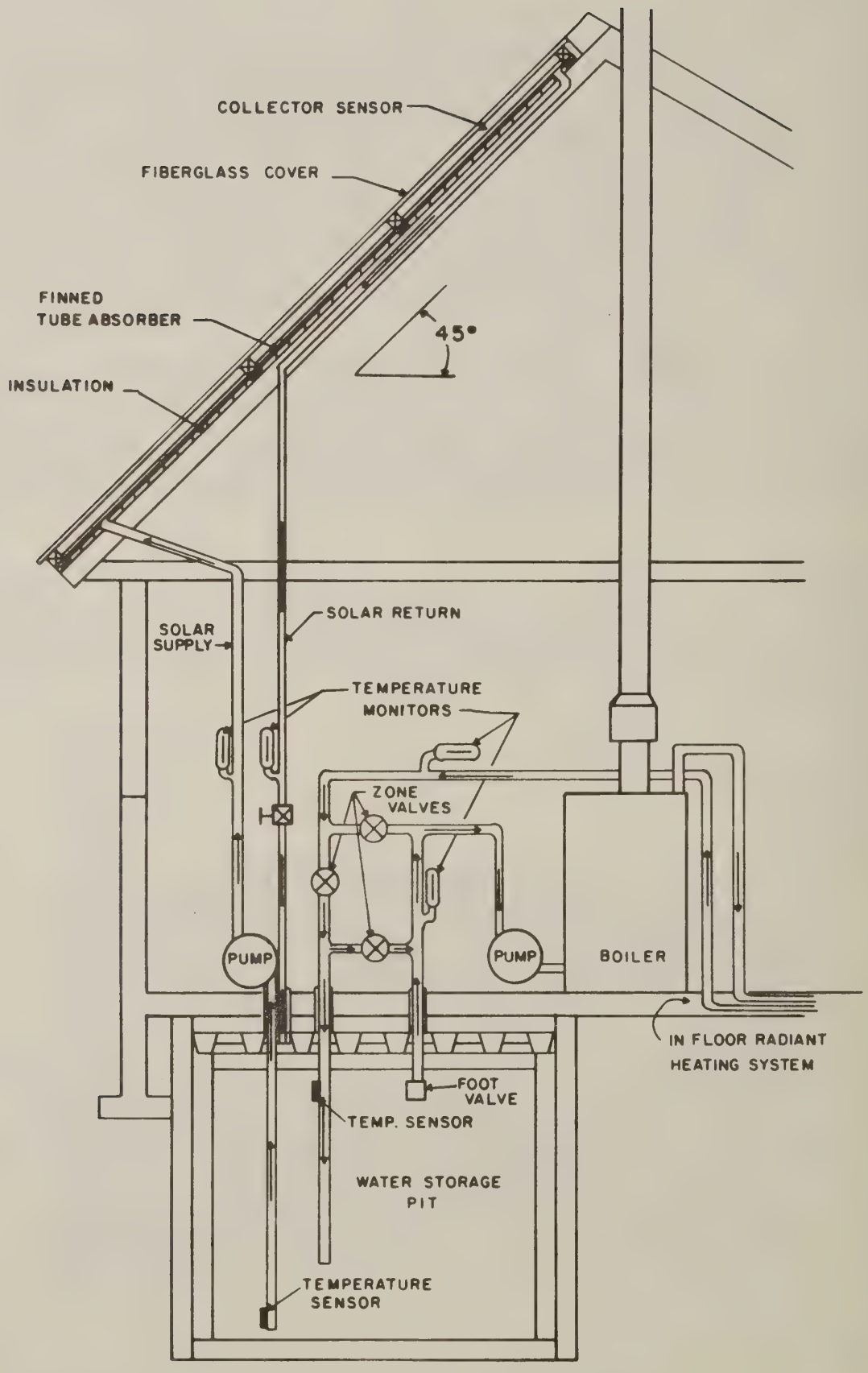


Figure 20. Cross section of Marley hot water solar system.

By the time the collectors were back in operation, the heating season was over and it was too late to get any monitoring data for this study. For this reason, no performance data is shown.

SUMMARY

At the beginning of this project, Jerry Marley hoped to achieve several objectives with the solar system on his new building. These objectives were to:

1. Provide a hot water solar collector that would furnish energy for the in-floor radiant heating system.

2. Provide hot water storage for use during nonsolar periods.

3. Provide an attic collector to preheat the ventilation air for farrowing and nursery rooms.

4. Provide controls for minimum management during operation.

When the collectors were first installed, they were not adequately supported which caused the 1/2-inch copper tubing to sag. After draindrown when the pump wasn't running, water remained in the collector causing the pipes to freeze and burst. By the time the collectors were repaired and put back in operation, the heating season and the project had ended. Therefore, it was not possible to measure the performance of this system.

The 6,000-gallon insulated storage tank, the solar attic, and the automatic controls were all successfully installed at the time the building was constructed and the entire system is now fully operational.

CONCLUSIONS

The problems that were encountered stress the need to be able to completely drain down a water-type collector system so it doesn't freeze up when it isn't operating during cold weather.

The problems also point out the importance of doing business with a reputable dealer. If this dealer had not backed up his product with service and materials, the producer would have been out a considerable amount of money. As it was, the dealer stood behind his product and repaired the system.

McKee Farm

Knox County, Illinois

GENERAL DESCRIPTION

The Dale McKee farm is located in northwestern Illinois in Knox County. The farrowing-nursery building is 40 by 168 feet (see Figures 21 and 22). There are six nursery rooms and three farrowing rooms that are used for production purposes. In addition, there is a workroom, and a 16-by-12-by-8-foot high rock storage used to store excess heat produced by the attic solar collector. The south section with the three farrowing rooms and two nursery rooms was built in 1977. Four nursery rooms on the north end of the building and the workroom and rock heat storage were added in 1980. Solar attics were incorporated into both sections of the building when they were constructed.

GOALS

The original farrowing-nursery unit with solar attic was already constructed when the demonstration project began. The main objectives that governed the design and construction of the added nursery unit and the roof heat storage were:

1. To incorporate additional solar collector area for preheating the ventilation air of the added nursery facility.

2. To add rock heat storage that could be used to store excess solar heat for use at night. This heat storage could be used for both the added nursery unit and the earlier constructed farrow-nursery unit.

3. To plan the system with controls so minimum management is required during operation.

4. To add on additional space for nursery pigs.

SOLAR SYSTEM DESCRIPTION

Because of the existing farmstead layout, the building was oriented with the ridge running north and south. Except for the roof area above the rock storage, fiberglass roofing was placed on both the east and west slopes of the roof making a solar attic. The roof above the rock storage is insulated and covered with metal roofing.

The working aisle is used as an air plenum to distribute the ventilation air to the farrowing and nursery rooms (see top section, Figure 22). During the winter, all ventilation air is pulled through the chimney ducts from the solar attic during the day and night. Variable speed fans mounted on the outer wall of each farrowing and nursery room create a negative pressure inside the rooms, causing air to be pulled from the working aisle through a slot at the top of the

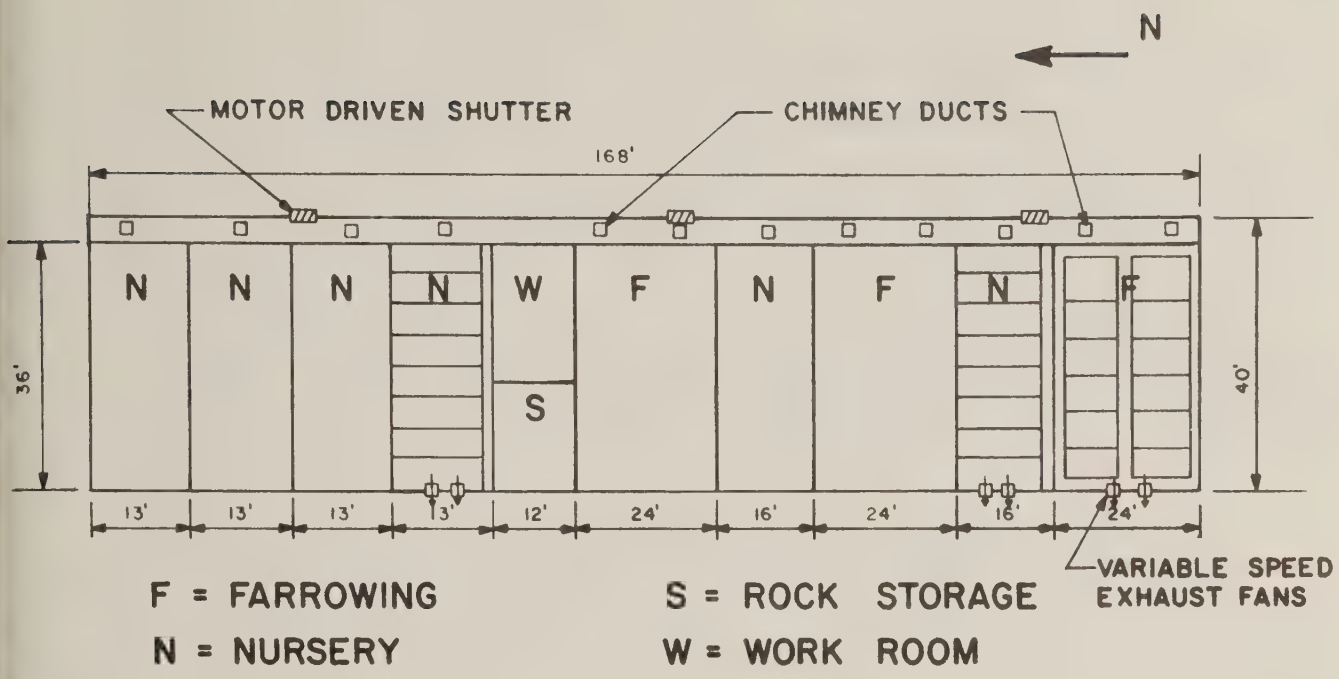




Figure 21. McKee solar-heated farrowing-nursery unit with rock storage: plan (top) and view from south end of building (bottom).

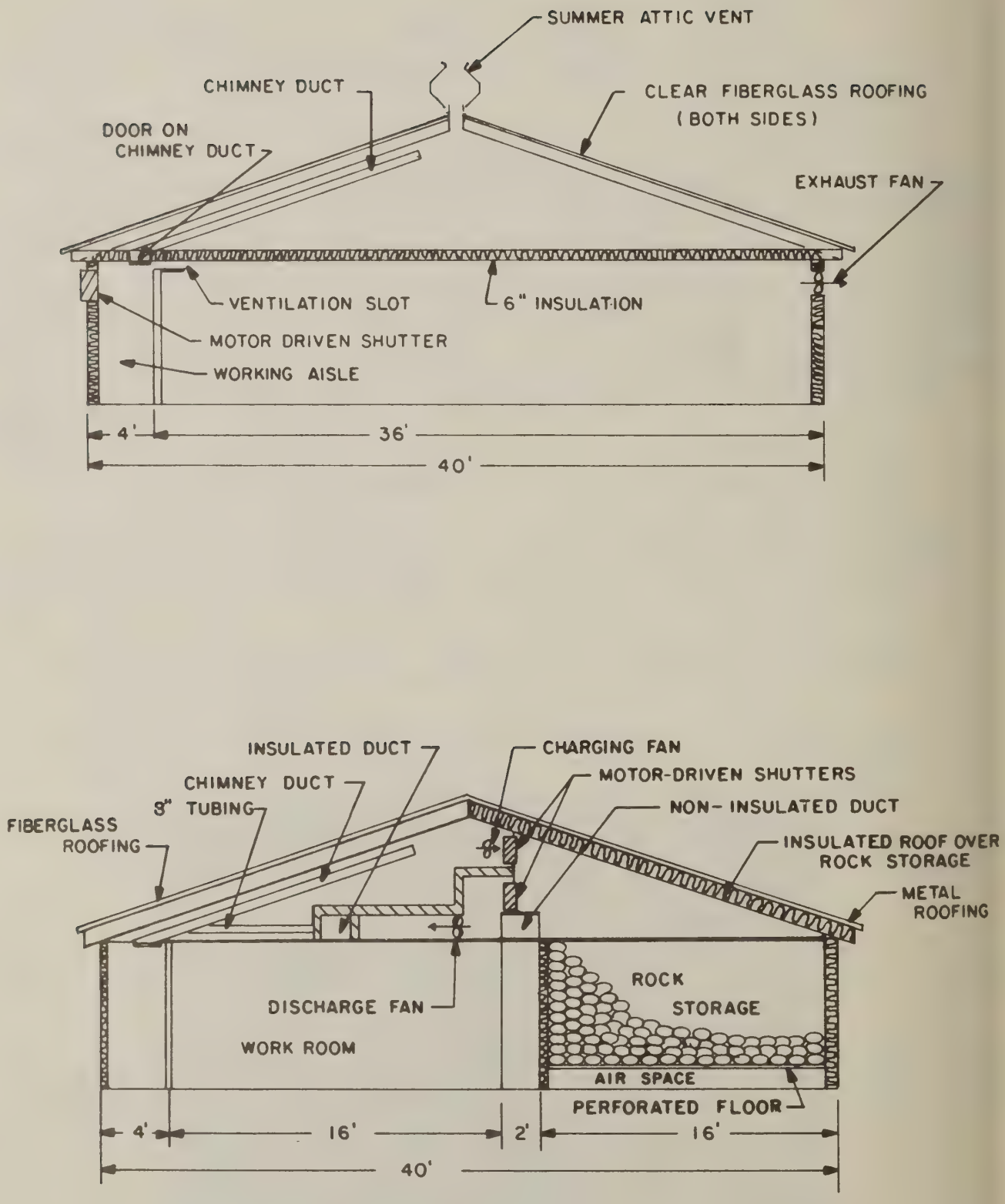


Figure 22. Cross section through farrowing-nursery portion of McKee solar-heated farrowing-nursery unit (top), and cross section through rock storage (bottom).

wall between the working aisle and the rooms. Chimney ducts extend from the working aisle into the solar attic and the same negative pressure created by the ventilation fans pulls air from near the attic peaks where it is warmest.

It is important to have a ventilation fan running continuously to maintain negative pressure so there is no chance for moist air from the farrowing or nursery rooms to flow backwards and enter the attic. This would cause moisture problems in the attic.

The motor driven shutters serve their purpose in the spring and fall when there is an occasional warm afternoon. When the temperature in the working aisle reaches the thermostat setting controlling the shutters, the shutters are opened and mostly fresh air is pulled in from the outside to keep the room temperature from becoming too warm.

During the summer, doors on the chimney ducts are manually closed and air is pulled from under the eave of the roof through a screened slot which on extends along the outer wall of the working aisle. This slot has hinged wooden doors which are manually opened or closed. When these doors are open, the ventilation air comes through the screened inlet under the eaves into the working aisle. When they are closed and the doors on the chimney ducts are open, the air comes from the attic. The attic has roof vents on the ridge that are opened during summer to allow warm air to escape. The newer nursery section also has a thermostatically controlled fan that helps ventilate this attic during the hot weather.

Rock Heat Storage

Excess heat produced in the solar attic is stored in a rock-filled room. This well-insulated, structurally strengthened room has been filled with 2-inch washed gravel. The heat storage system operates in two modes - charging and discharging (see botton section, Figure 22). The charging system is controlled by a differential thermostat that senses the air temperature in the attic and compares it with the temperature at the bottom of the rock storage. The charging fan is then activated whenever the attic temperature is higher than the temperature at the base of the rock storage. When this fan operates, air from both attic collectors is blown down through the rocks and returned to the attic areas through uninsulated ducts. These uninsulated ducts extend some 50 feet into each attic area directing the cooler air coming from the bottom of the rock storage back into the two attic areas away from the charging fan. This reduces the chance of short circuiting the heat storage charging system.

The heat storage discharge system is controlled by a time clock. The discharge fan is preset to be off during the day and on at night. When this fan is operating, warm air is pulled from the top of the rock heat storage and blown through two insulated ducts which move the air away from the heat storage through each of the attic areas. These insulated ducts are connected to the chimney ducts via nonperforated 8-inch plastic drainage tubing. These tubes take the warm air from the insulated ducts and direct it into the chimney ducts which are pulling the ventilation air down into the working aisle. The entire heat storage system can be disconnected from the power supply during the summer to avoid

electrical waste and overheating. Also, during the summer, thermostatically controlled attic fans operate to help prevent overheating in the attic.

SOLAR SYSTEM COST

The cost of the solar portion of the farrowing-nursery unit, the newer nursery unit and the rock storage is $9,277. This amounts to $1.43 per square foot of collector. A listing of costs is shown below:

Materials and Labor (rock storage)	$7,100
Fiberglass Cost minus Metal Roofing Cost (6,480 ft^2)	324
Duct Work	853
Estimated Labor	1,000
	$9,277

SOLAR SYSTEM PERFORMANCE

The solar system on the McKee farrowing-nursery building was monitored during the winters of 1979-80, 1980-81, and 1981-82. Air temperatures, air flow from the solar system, and solar radiation levels were measured during the periods of April 4-9, 1980; March 23-April 1, 1981; and February 11-28. 1982.

Figure 23 shows a 2-day performance curve of the heat storage during the winter of 1980. The discharge from the heat storage is controlled by a time clock, with heated air coming from the rock storage only at night when there is no solar heat. The temperature of the ventilation air on the curve in Figure 23 is influenced by the heat storage during the night and by the solar attic collector during the day. This allows the ventilation air being delivered from the solar attic to be warmer than if the ventilation air was pulled from the rock storage.

From these measurements, calculations were made which indicate the solar system added slightly less than 38 million Btu of heat energy to the ventilation air during these 34 days. The total amount of available solar radiation striking the roof during this period was around 181 million Btu. This represents an efficiency of 21 percent.

However, when each monitoring period is examined separately, results are somewhat different. In 1980 and 1982, when the outside temperature averaged 46°F and 34°F respectively, the solar system operated at 24 percent efficiency. During the 1981 monitoring, when the outside temperature averaged a warmer 53°F, the solar system operated at only 16 percent efficiency. One reason for this difference may be that the unusually high outside temperature in 1981 reduced the need for the heat from the rock storage.

Since the rock heat storage system can actually be of benefit at some periods other than during the normal heating season, the overall efficiency of the solar system from October through April has been figured at the higher efficiency rate of 24 percent. At this rate, the amount of energy provided by the solar system to heat the ventilation air is equivalent to 3,694 therms of natural gas per

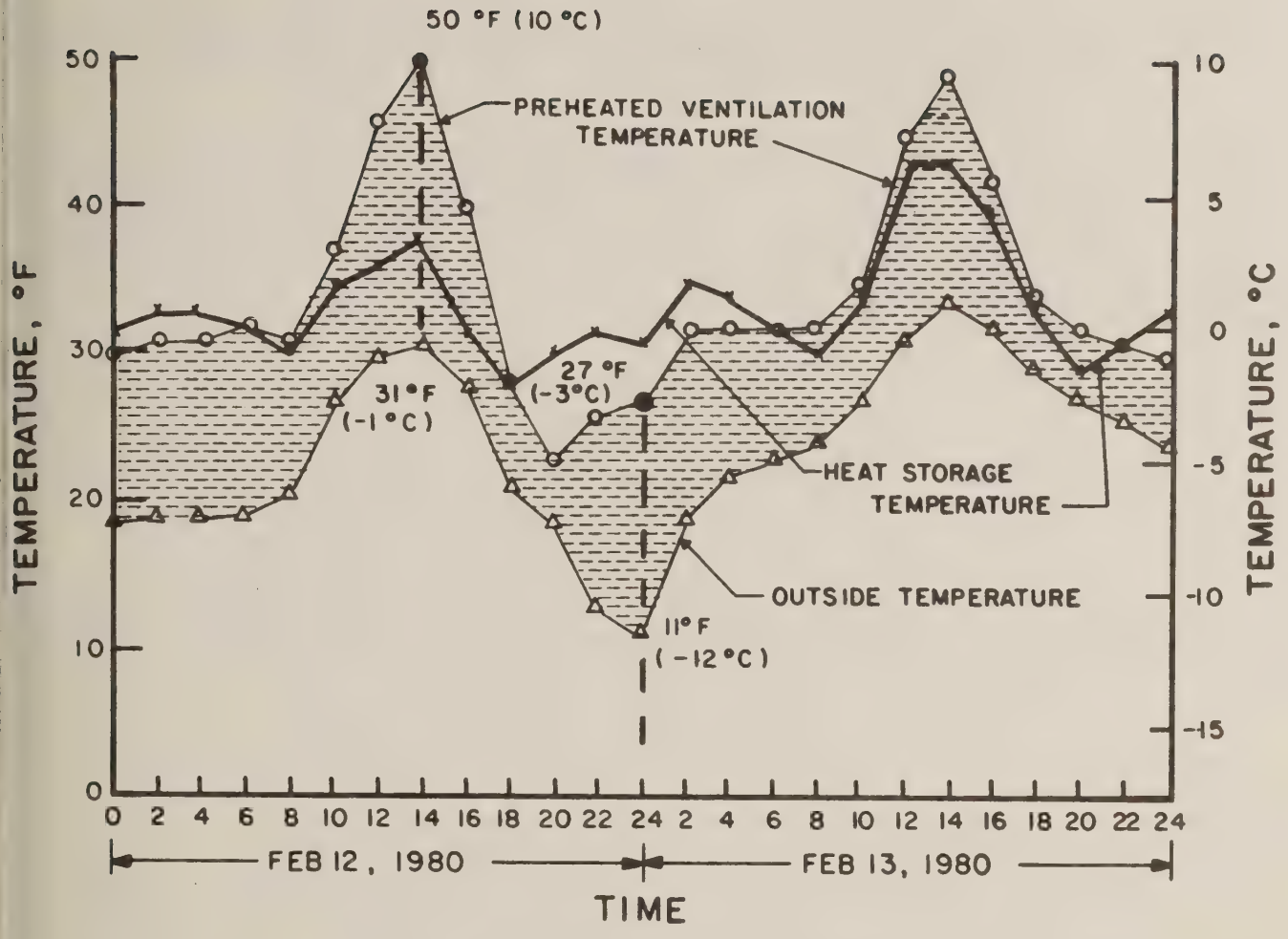


Figure 23. Performance of McKee solar attic system with rock heat storage, February 12 and 13, 1980.

heating season. Calculations for this system were based on natural gas because this is what the producer used as his fuel source. If natural gas is priced at only $0.45 per therm, the value of the heat provided by the solar system is worth $1,662.30 per heating season. Thus, only 5.6 heating seasons are required for simple payback on the original investment of $9,277.

SUMMARY

The goal when incorporating the solar attic into the building was to provide an inexpensive means of preheating the ventilation air. The rock heat storage system was constructed in order to store excess heat produced in the solar attic. This excess heat is utilized to preheat ventilation air at night. In addition, the system was designed to operate with a small amount of management.

The solar attic and rock heat storage system operated at an efficiency level of around 24 percent. At this rate, the amount of energy provided by the solar system to heat the ventilation air is equivalent to the energy available in 3,694

therms of natural gas per heating system. Extending this amount of energy saved over time indicates that a simple payback on the initial cost of the system would occur in approximately 5 1/2 heating seasons.

The final goal to be discussed is that of minimum operational requirement. Since all air movement is controlled by thermostats and timers, the only required management is to set, check, and maintain the thermostats, timers, fans, and dampers. It is wise, when investing this amount of money, to purchase quality equipment. Also, deal with a reputable builder, especially, when constructing an aboveground rock storage in your building.

CONCLUSIONS

The rock storage system provided temperature rises to the ventilation air during the night (when most needed) that were almost equal to the daytime temperature rises.

The last-heat-in and first-heat-out operating mode does, however, permit much more fluctuation in temperature than was present in the "one direction airflow" on the Borgic system.

PERFORMANCE DATA

Solar System Efficiency Level: 24%

Collector Size: 6,480 ft^2 Solar System Cost: $ 9,277

Assumptions

1. Temperature of ventilation air to farrowing room needed to achieve comfort zone -- 68°F
2. Heating season (HS) is October through April
3. Natural gas (N.G.) as an average conventional fuel source provides 80,000 Btu/therm
4. On a horizontal surface, approximately 190,000 Btu/ft^2 are available from October through April
5. 1 therm of natural gas costs $0.45

Payback Calculation

$$\frac{190{,}000 \text{ Btu}}{ft^2\text{-HS}} \times .24 \times 6{,}480 \text{ } ft^2 \times \frac{1 \text{ therm N.G.}}{80{,}000 \text{ Btu}} = 3{,}694 \text{ therms N.G./HS}$$

$$\frac{3{,}694 \text{ therms N.G.}}{\text{HS}} \times \frac{\$0.45}{\text{therms N.G.}} = \$1{,}662.30/\text{HS}$$

$$\frac{\$9{,}277}{\$1{,}662.30/\text{HS}} = 5.6 \text{ heating seasons until payback}$$

Meyer Farm

Adams County, Illinois

GENERAL DESCRIPTION

The Meyer farm is located in western Illinois in Adams County and is operated by Louis and Marvin Meyer. This is a 50-cow dairy where the cows are housed in a 48-by-72-foot open front free stall barn and are milked in an adjoining milking parlor which is part of the 30-by-36-foot concrete block milking center (Figure 24).

The milkroom and milking parlor must be kept above freezing. In addition, the operator raises the temperature of the milking parlor to a comfortable level at milking time (about 55°F) by manually turning the thermostat controlling an L.P. gas heater. Because the milking times are at 5:00 to 6:00 in the morning and 5:00 to 6:00 in the evening, any solar collector must have some type of heat storage in order to provide adequate heat at these times of the day.

A free-standing, double-glazed covered plate collector with rock storage was constructed next to the milking center. The wedge shaped collector was sloped 50 degrees as shown in Figure 25. Approximately 8 tons of 3-inch washed gravel was placed in the collector and two 40-gallon water tanks (about 18 inches in diameter and 36 inches long) were embedded in the top of the gravel. Both the gravel and the water serve as heat storage. The collector has a 12 by 16 feet solar collection area for a total area of 192 square feet.

The collector surface of clear corrugated fiberglass has a 1 1/2-inch dead air space which serves as an insulting layer, separating it from a layer of clear flat fiberglass. Another 1 1/2-inch air space behind the flat fiberglass serves as the air channel for the air to pass through the collector where it is warmed when the sun is out. Behind the air channel is a 1/2-inch layer of black-painted polyurethane insulation board which serves as the absorber plate.

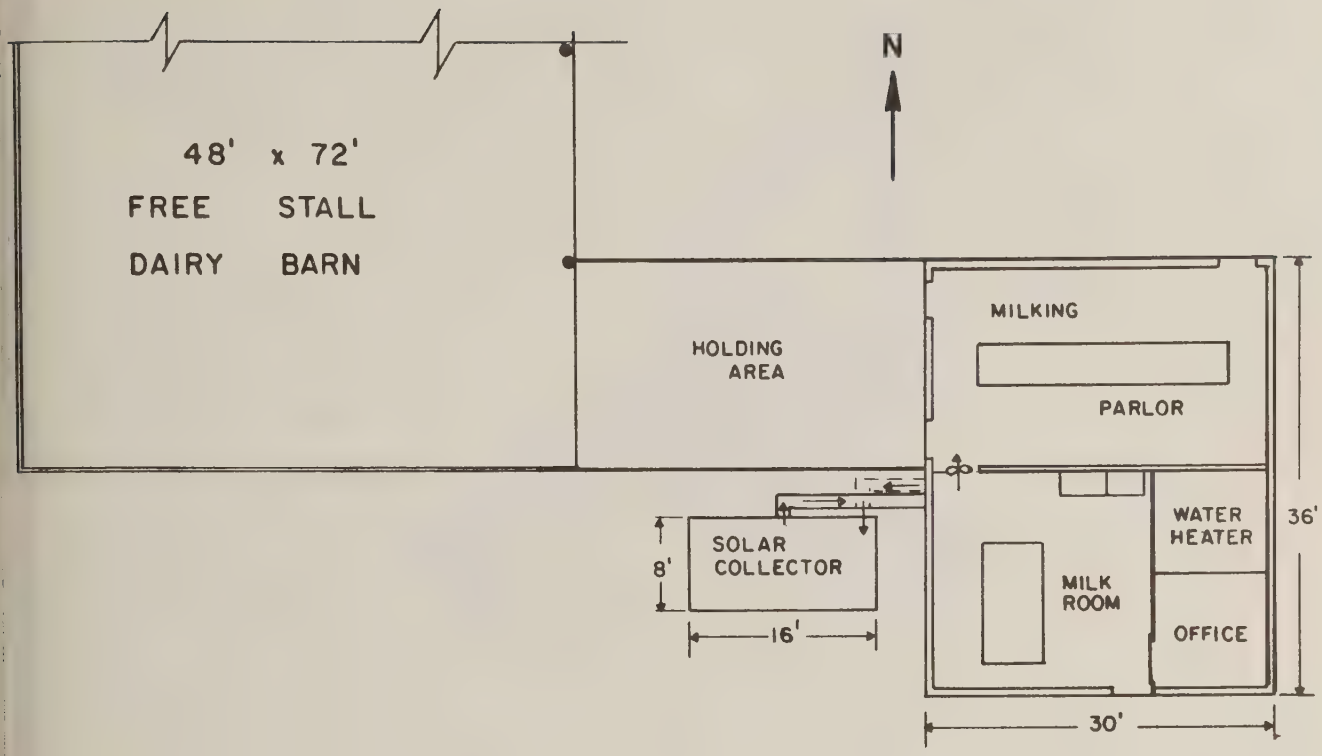
A rock retaining wall creates a vertical air chamber at each end of the collector-storage unit. The floor of the rock storage is a perforated metal floor which forms a return air duct to the air chamber on the east end. The air chamber at the east also contains a horizontally mounted condenser.

GOALS

The following objectives governed the design and construction of this solar system:

1. To provide some solar heated air to help keep the milkhouse and milking parlor from freezing during cold weather.

2. To provide some heat storage in order to utilize the solar heat during the nonsolar hours of the day. Not only is it necessary to keep the



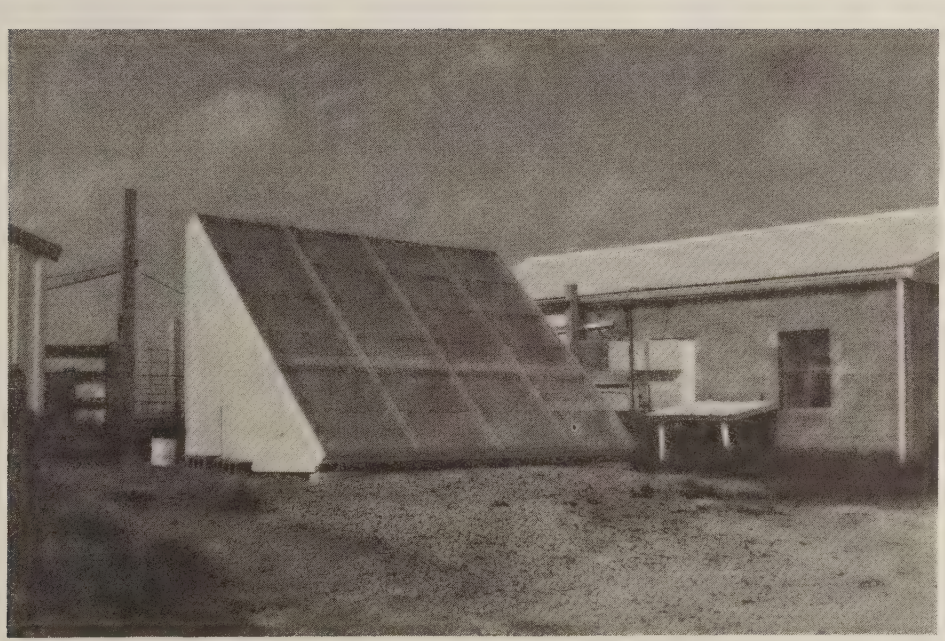


Figure 24. Meyer dairy unit with solar collector and rock storage: plan of overall layout (top), and view of solar collector and milking center (bottom).

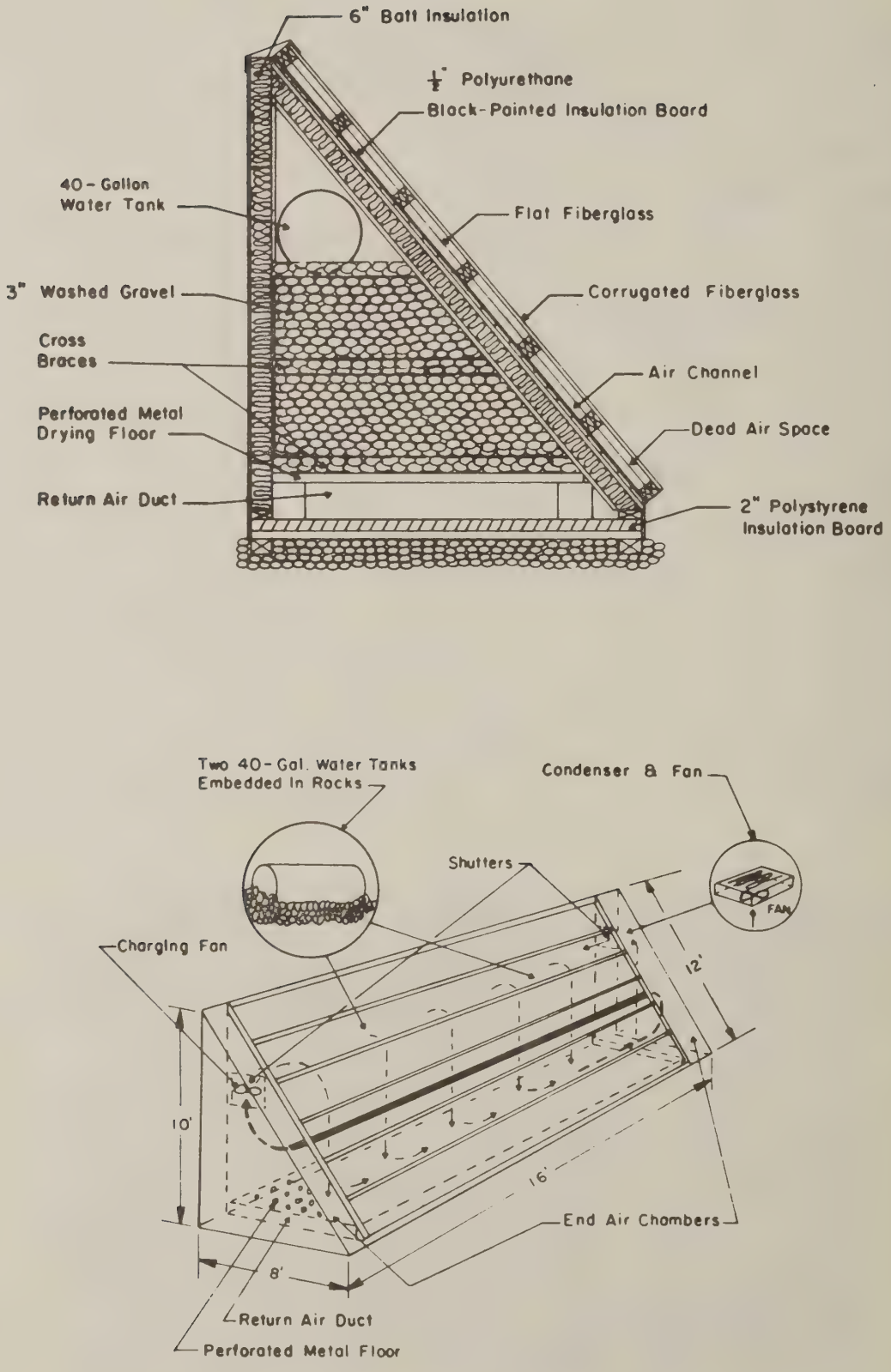


Figure 25. Cross section of Meyer solar collector with rock storage (top), and airflow pattern through collector (bottom).

milking center from freezing but extra heat is also required for operator comfort in the milking parlor during the typicaly nonsolar milking period.

3. To preheat some water for use in the milking center.

4. To recover some of the heat generated by the milk cooler's condenser.

5. To provide controls so minimum management is required during operation.

SOLAR SYSTEM DESCRIPTION

The 50-degree sloped, free-standing double-glazed collector is being used to provide warm air for heating the milking center and to preheat the water used for prepping the dairy cows and cleaning the building. Because the demand for heating and hot water usage occurs during nonsolar periods, 8 tons of 2-inch washed gravel and storage capacity for 80 gallons of water have been placed inside the collector to serve as heat storage mediums. To charge these mediums with heat, two methods are utilized. By the first method, the thermostatically controlled charging fan mounted on the west inner wall blows warm air over the two 40-gallon tanks and down through the rocks. The air flows down through the metal perforated floor into the return air duct which leads to the vertical air chamber on the east end. From there it moves across the solar absorber into the west air chamber from where it returns to the charging fan for another cycle (see Fig. 25). The charging fan is controlled by a differential thermostat which senses the temperature of the air below the rock storage and in front of the solar absorber. When the air temperature in front of the absorber is higher than the air temperature below the rocks, the fan is automatically turned on and the water and rocks are charged with heat.

The second method of supplying additional heat to the storage unit involves the milk cooler. A second condenser-fan unit is mounted in the air chamber on the east end of the collector and has been connected in series with the cooler's condenser. When the cooler is operating, Freon from the cooler runs first through the condenser mounted in the solar collector then to the original outdoor condenser. The fan mounted behind the condenser blows air through it extracting heat from the Freon. This heated air is blown down past the water tanks and through the rocks where it releases heat. The air then moves through the perforated floor and back into the air chamber on the east end, where the cycle is repeated (see air flow pattern in Figure 25). This system can be disconnected from the milk cooler's Freon system by manually adjusting a valve. This would be done if repairs were required or if the feasibility of operation became questionable, such as in the summer when the rock storage on the solar system is already at a very high temperature.

Two ducts have been constructed from the collector to the milk room to utilize the heat stored in the rocks. Two thermostats wired in series so as to perform as a differential thermostat control the fan that blows air from the top of the rock storage to the milk room. This fan operates when the milk room requires heat and the temperature above the rocks is warmer than the temperature in the milk room. The second duct is used to return air from the milk house to

the east air chamber. Once the heated air is in the milk room, it can be blown into the milking parlor with a manually controlled fan. However, air is not returned from the milking parlor to the milk room and back to the solar collector for sanitation reasons. Gravity shutters are used with all fans to prevent back drafts.

The two tanks on top of the rocks are connected in series. Solar energy preheats the water in the tanks before it enters the water heater. All of the plumbing to and from the water the heater has been installed in the insulated ducts connecting the solar collector to the milk room. This prevents the pipes from freezing and bursting. In addition, a valve arrangement has been installed to shut this preheat system off from the rest of the system if repairs are necessary or if the operator decides to drain the system down. Frost free valves have been installed to facilitate draining the system.

SOLAR SYSTEM COST

The solar collector and rock storage for this system cost was $6,000. This breaks down to a cost of $31.25 per square foot of collector. A listing of costs is shown below:

Fiberglass and Accessories	$ 378.51
Building Materials	1,847.12
Plumbing Materials	337.49
Electrical Materials	1,101.15
Estimated Labor	2,335.73
	$6,000.00

SOLAR SYSTEM PERFORMANCE

The amount of heating fuel used in the Meyer milking center was recorded prior to the completion of construction of the solar system. Monthly useage was recorded during both summer and winter periods. After the solar system was put into use, fuel readings continued to be recorded. In addition, air temperatures, air flow from the solar system to the milkroom, and solar radiation levels were measured. Since this was a new system where fuel readings could be obtained both before and after construction of the solar system, all of the performance calculations are based on these fuel readings.

The fuel saving during the winter was determined by using a 45 degree-day (dd) base for both the periods before and after the solar system was in operation. The fuel savings were calculated by multiplying the difference in these two values (which amounted to 0.50 ft^3/dd) by the average degree days per year using a 45°F base (1677 dd/yr). The cubic feet of L.P. gas saved per heating season is converted into gallons of L.P. gas and then into dollars saved per year (which amounted to $13.82 per year). These calculations are shown in the Performance Data section.

The water heating savings were determined by the fuel used before and after construction of the solar system during the month of July. This value was

extended over a period of five months. The savings in energy for water heating per year was then calculated to be $4.61.

Combining these savings indicated a very poor system payback. Part of the reason for such a long payback period can be seen in Figure 26. In December, the solar collector was capable of delivering air at a temperature in excess of 80°F during a sub-freezing day. However, because the milking center only needed to be kept above freezing, much of the heat produced by the solar system was not being utilized lowering the overall efficiency.

SUMMARY

The solar system on the Meyer farm was a well designed and constructed collector that fulfilled the goals set forth at the beginning of the project. Unfortunately, the high cost of the collector and the small amount of solar energy utilized by the milking center made the total solar system not economical.

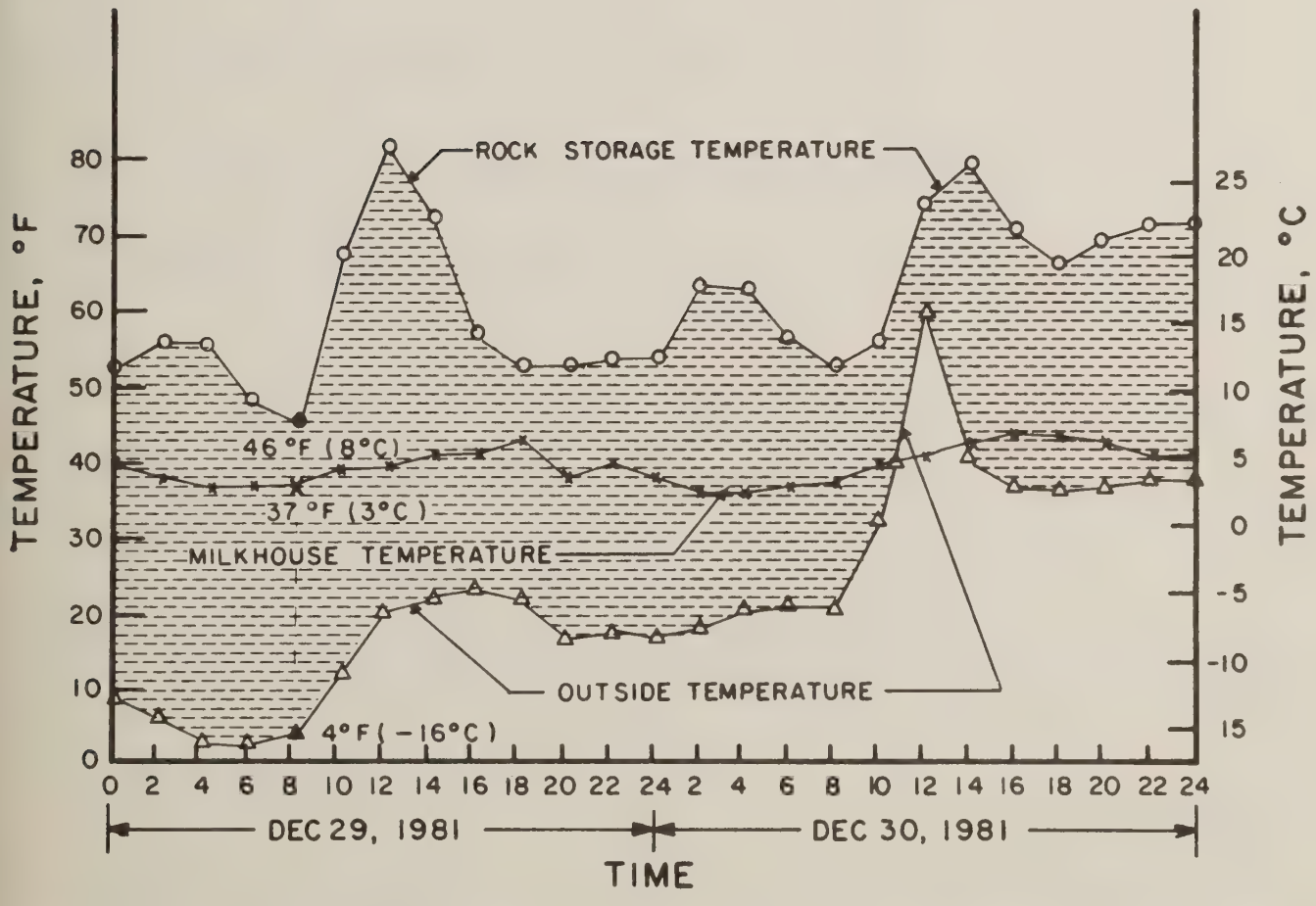


Figure 26. Performance of Meyer collector with rock storage, December 29 and 30, 1981.

The Meyers' solar collector with rock storage resembles the lean-to collector constructed on the side of the swine nursery building at the Borgic farm that has an estimated payoff period of six years. This collector was not built with farm labor as was the Borgic unit, but was constructed by a builder, increasing construction costs. The water tanks and the extra condenser also added extra costs to the unit.

The long term required for payback to occur vividly points out the problem of using this air-type of solar collector with rock storage for their milking center. In addition to the high cost of construction, there were additional factors that extended the time required to pay back the initial investment costs.

These factors are:

1. The operator desired immediate heat for comfort at milking time and the solar system could not meet this demand.

2. Each time a group of cows were turned out of the milking parlor and a new group brought in, the room would be cooled considerably and increase the need for immediate heat.

3. There are usually only four months during the year when below-freezing temperatures occur on a regular basis, thus limiting the time when the solar system is used for freeze protection.

4. The amount of benefit derived from the solar system for water heating is much less than expected.

A low-cost air-type solar system for a calf barn or commercial water-type solar collector used to preheat water for the milking center may both be economically feasible for a dairy farm. But, before a dairyman invests in either of these sources of energy, he should first install the proper amount of insulation and install a milk heat-recovery system.

CONCLUSION

The solar system on the Meyer dairy milking center was much too costly to be economically feasible at present costs. Some benefit may have been received by the milk heat-recovery system, but a standard commercial milk heat-recovery system can do this at a lower cost.

The concrete block structure had considerable window area, no wall insulation and poor ceiling insulation. Money spent properly insulating the building would have provided more benefit for the investment than did the solar unit.

PERFORMANCE DATA

Collector - 192 ft^2 Solar system cost $6,000

Assumptions

1. Heating of the milking center is calculated on a 45°F degree day base
2. There are 1677 degree days (dd) per year
3. L.P. gas as an average conventional fuel source provides 73,600 Btu/gal
4. 1 gal. of L.P. gas costs $0.60
5. 36.4 ft^3 of L.P. gas comprise a gallon
6. Calculations for solar water heating are based on benefits being derived over a five-month period.

Winter Heating

Fuel Useage

Before Solar System -- 1.14 ft^3/dd
After Solar System -- 0.64 ft^3/dd

Savings

1.14 ft^3/dd - 0.64 ft^3/dd = 0.50 ft^3/dd

$$1677 \text{ dd/yr} \times 0.50 \text{ ft}^3\text{/dd} \times \frac{1 \text{ gal L.P.}}{36.4 \text{ ft}^3} \times \frac{\$0.60}{\text{gal L.P.}} = \$13.82\text{/yr}$$

Summer Water Heating

Fuel Useage

Before Solar System (July 1980) -- 128 ft^3
After Solar System (July 1982) -- 72 ft^3

Savings

128 ft^3/month - 72 ft^3/month = 56 ft^3/month

$$56 \text{ ft}^3\text{/month} \times \frac{1 \text{ gal L.P.}}{36.4 \text{ ft}^3} \times \frac{\$0.60}{\text{gal L.P.}} \times 5 \text{ months} = \$4.61$$

Total Savings per Year

Winter -- $13.82

Summer -- 4.61

$18.43/year

$$\frac{\$6{,}000}{\$18.43\text{/year}} = 325 \text{ years until payback}$$

Snell Farm

Sangamon County, Illinois

GENERAL DESCRIPTION

The Sam and Philip Snell farm is located in central Illinois in Sangamon County. Their 47-by-281-foot swine confinement building has six nursery rooms, eight farrowing rooms, a breeding area, and an area used for holding sows and weaning pigs as shown in Figure 27. The south facing solar roof is built at at 45 degree angle to the horizontal, providing a more favorable solar angle to the sun during winter than do most normal roofs. The building has 36 double-glazed 4-by-10-foot solar hot water panels in the center section of the south roof.

Originally there was a little over 1,000 square feet of a covered plate collector for heating the ventilation air on each end of the south roof. The covered plate collector on the west end of the south roof was retrofitted with 18 single glazed 4-by-10-foot solar hot water panels painted with a black chrome selective surface paint. The total area of this portion of the roof is 1,050 square feet, but only 720 square feet of actual solar panels were installed in this area because of the need to provide space for the manifold pipes and the extra space required to slightly tilt the 4-by-10-foot vertically mounted panels. Tilting the panels allows them to drain down, which prevents them from freezing during cold weather when the system is not operational.

The construction of the panels and controls for the system is the same as the solar system described in the Jerry Marley unit. The one major difference was the vertical mounting of the 4-by-10-foot hot water solar panels on the Snell building.

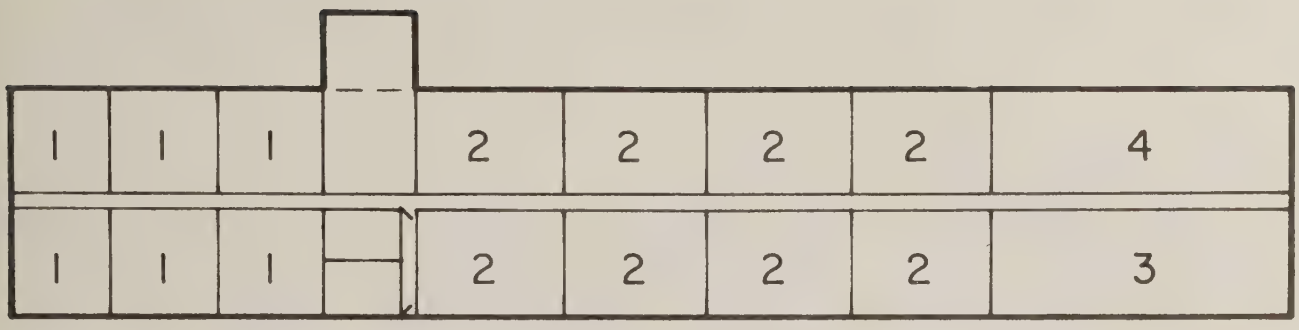
A well insulated 5,000-gallon hot water storage tank was constructed under the floor of the boiler room. The solar hot water system works in conjunction with the hot water boiler which delivers hot water to an in-floor heating system in the farrowing and nursery rooms.

GOALS

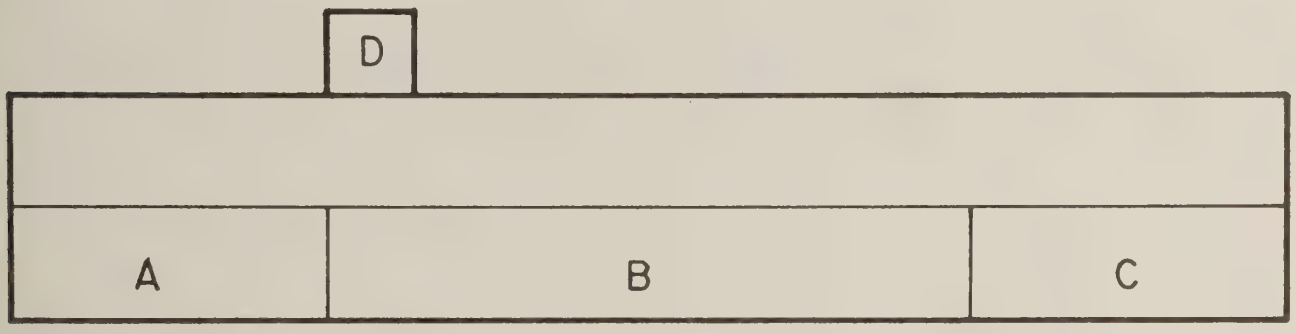
The Snell confinement unit with solar hot water collectors in the center roof section and covered plate collectors for preheating the ventilation air at both ends of the roof was already constructed when the demonstration project began. The main objectives that governed the addition of more hot water solar collectors and the data collected during monitoring were:

1. To add more solar hot water collectors to supply more energy for the in-floor radiant heating system.

2. To install the new collector panels with a black chrome selective surface and single glazing and compare this to the older panels with nonselective surface and double glazing.



1- NURSERY 2- FARROWING 3- BREEDING 4- SOW CRATES & WEANING PENS



A - 18 SOLAR PANELS - WATER 1050 ft^2 SINGLE GLAZE

B - 36 SOLAR PANELS - WATER 2100 ft^2 DOUBLE GLAZE

C - SOLAR AIR 1050 ft^2

D - WATER STORAGE TANK 5000 gal.

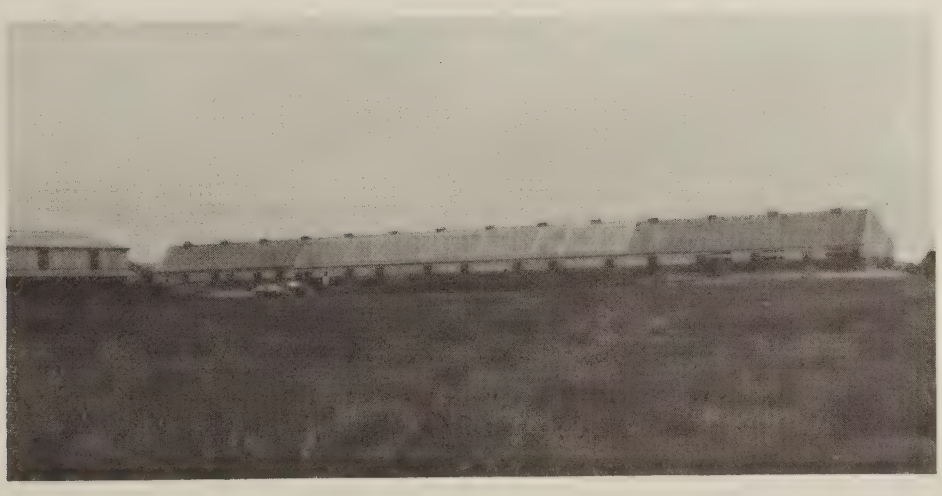


Figure 27. Snell solar-heated swine building: floor plan (top), roof plan (middle), and overall view (bottom).

3. To provide controls so minimum management is required during operation.

SOLAR SYSTEM DESCRIPTION

The solar hot water system being monitored consists of eighteen 4-by-10-foot finned-tube hot water absorber panels constructed with 1/2-inch copper tubing with a copper absorber plate soldered to the tubing. The copper absorber plate and tubes were painted with a black chrome selective surface paint.

The operation of the solar system (Figure 28) is very similar to the Marley unit. A self-priming pump controlled by a differential thermostat delivers water to the solar panels when the temperature in the collector is warmer than the temperature of the water at the bottom of the storage tank. When the temperature of the solar panels falls below the temperature of the water in the bottom of the storage tank, the pump turns off, a solenoid valve opens along the top manifold connecting all of the absorber panels, and all the water drains back into the

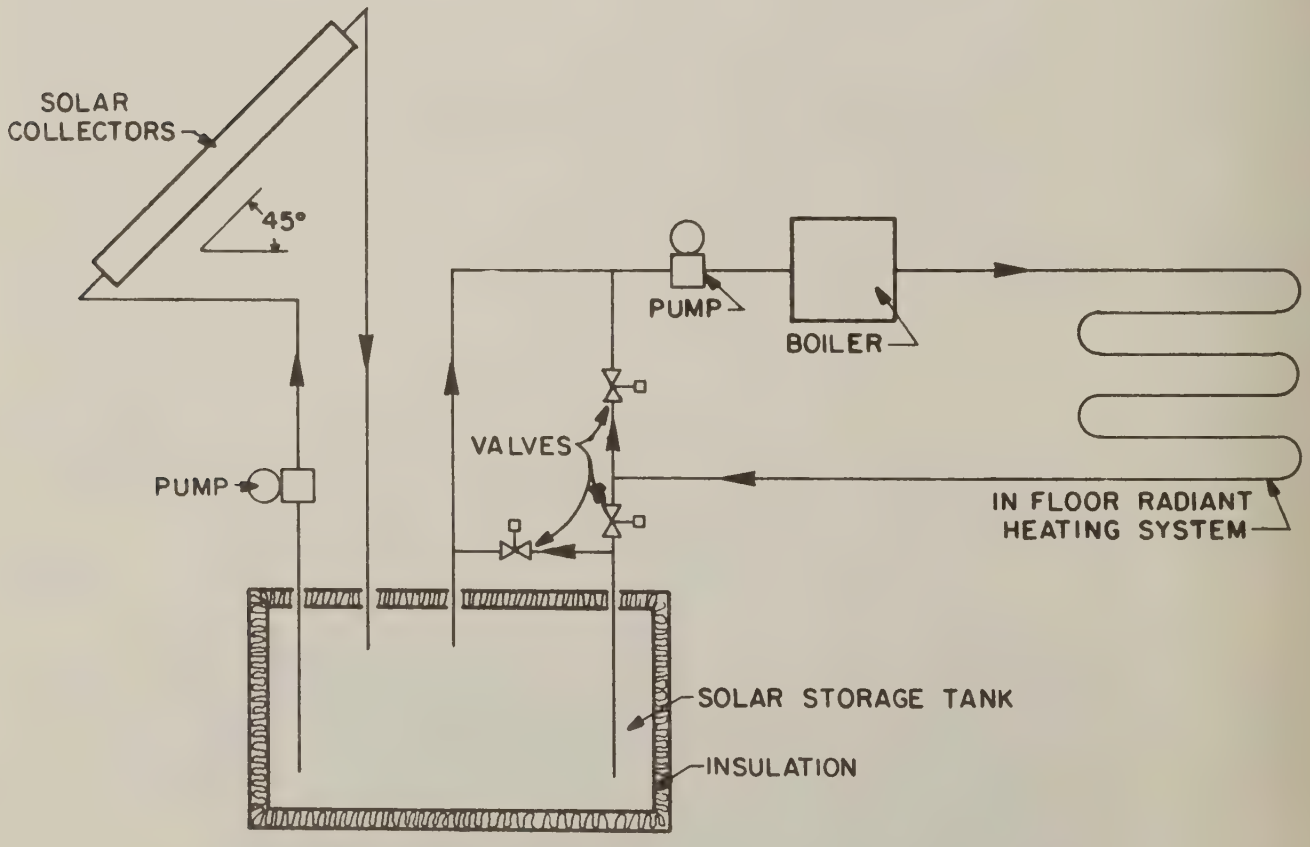


Figure 28. Schematic of Snell hot water system.

storage tank. This pump delivers 14.5 gallons per minute, or 0.02 gallon per minute per square foot of absorber.

Solar heated water is used in an in-floor radiant heating system in the farrowing and nursery rooms. If additional heat is required, a boiler heats the water to the proper temperature. A second differential thermostat controls the zone valves, allowing either the water from the top of the storage tank or the return water from the in-floor heating system to be delivered to the boiler, depending on which is warmer. The water from the boiler is pumped through the floor heating system and provides zone heating for the little pigs.

SOLAR SYSTEM COST

The cost for adding the new hot water solar collector panels was $9,637.50. This figures out to a per-square-foot cost of $9.17 for the total collector area. A breakdown of costs is shown below:

Absorber, Insulation, Plumbing	$8,160.00
Labor	1,275.00
Concrete	150.00
Fiberglass Cost minus Metal Roofing Cost (1,050 ft^2)	52.50
	$9,637.50

SOLAR SYSTEM PERFORMANCE

This hot water solar system was monitored during the winter of 1980-81 and the summer of 1981. Both the amount of available solar radiation striking the collector surface and the amount of Btu delivered from the collector to the insulated water storage tank were measured.

The monitoring periods were December 20, 1980, to March 12, 1981; and April 8 to August 3, 1981. The total amount of available solar radiation striking the collector during the 83 days monitored in the winter was around 118 million Btu. The amount of energy delivered by the water-type solar collector during this period was 19.3 million Btu. This represents an efficiency of 16 percent for winter use. During the 118 days monitored in the summer, the total amount of available solar radiation striking the collector was 185 million Btu and 46.2 million Btu of energy were delivered to the insulated storage tank. The collector's efficiency level thus improved during the summer to 25 percent. There was no way to determine whether all the energy collected was used.

Figure 29 shows the performance of the hot water collector for a 16-day period in the winter of 1980-81. During this period, the average daily temperature varied from a high of 35°F to a low of 9°F. As shown in the graph, the amount of solar energy collected follows the amount of solar energy available more closely than it follows the average outside temperature. The total amount of energy delivered by the solar system for the entire year, if we assume 25 percent collector efficiency for the summer and 16 percent efficiency for the winter, would be equivalent to 1,763 gallons of L.P. gas. A simple payback

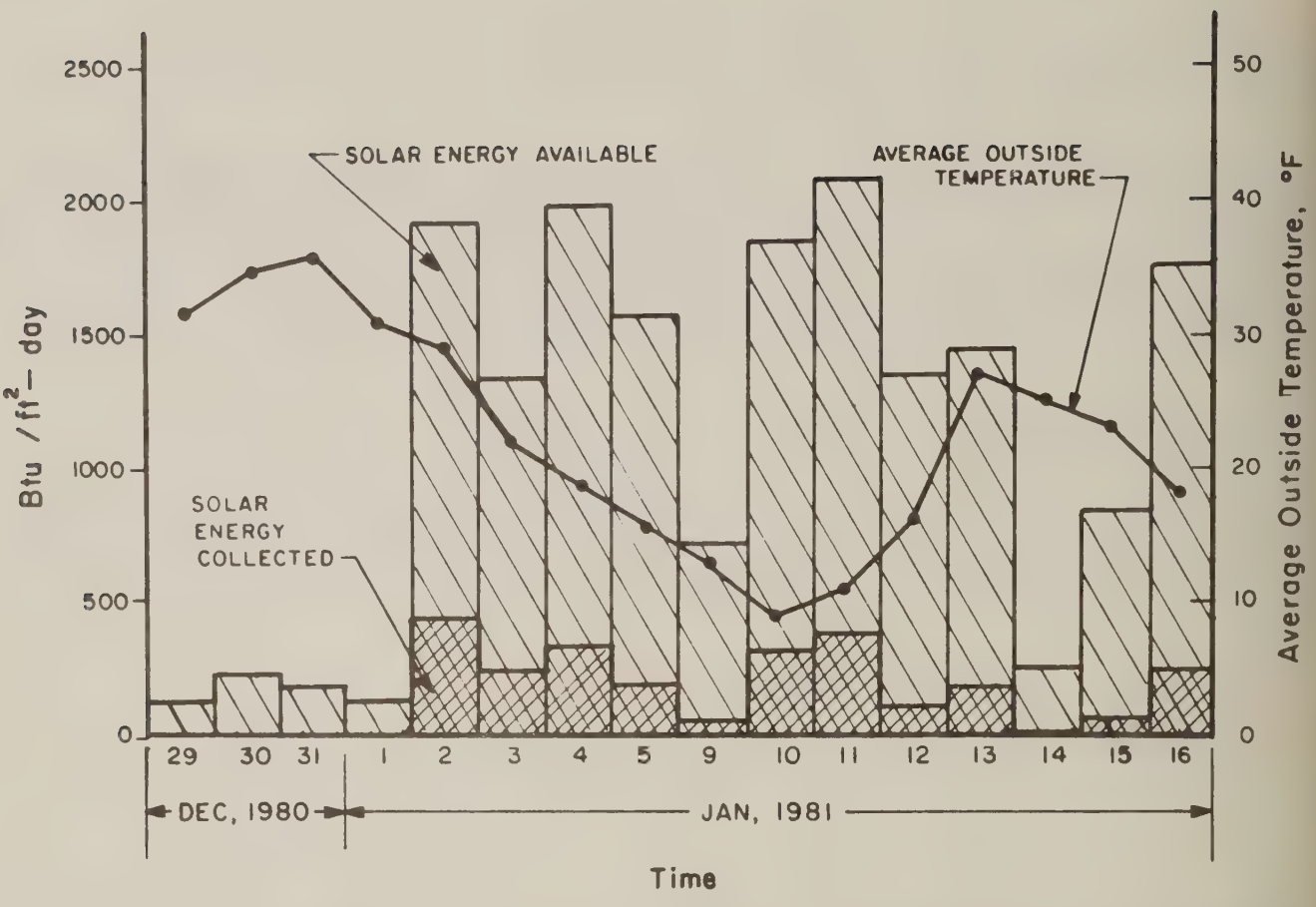


Figure 29. Performance of Snell hot water solar heating system, December 29 through January 16, 1981.

period, not charging for interest on the $9,637.50 investment would take nine years.

SUMMARY

When the solar roof on the west end of the Snell hog building was modified to serve as an additional solar hot water system, the main goals were to:

1. Provide additional hot water solar collector area that would furnish more energy for the in-floor radiant heating system.

2. Compare the performance of single glazed, solar panels with a black chrome selective surface and double glazed panels with a nonselective surface.

3. Provide controls for minimum management during operation.

The new water solar collector was monitored both during the winter and the summer. Measurements indicate that the collector operates at a 16 percent efficiency level in the winter and 25 percent efficiency level during the summer. For example, during the summer the collector is able to deliver 25 Btu of heat energy for every 100 Btu of solar energy which strikes the collector's surface. Calculations were made by extending these efficiency levels over the entire year and show the amount of energy collected equivalent to the energy available from 1,763 gallons of L.P. gas. Thus a simple payback, not charging for interest on the $9,637.50 investment would be nine years. This is assuming that all of the energy collected is used. We were not able to compare the performance of these collectors with the original double glazed collectors on the center roof section which did not have the special black chrome selective surface.

Hot water needs to be at a minimum temperature of about 110°F to be useful for in-floor radiant heating. If the temperature of the water returning from the in-floor heating system is at 100°F and the temperature of the water in the storage tank is 90°F, the return water will be rerouted through the boiler and the heat stored in the water storage tank cannot be used. If however, radiators were installed in the ventilation system to preheat the ventilation air, the 90°F water could furnish heat energy that would be useful.

CONCLUSIONS

This system appears to be economically feasible if all of the energy collected can be used. The overall efficiency could be improved in winter by utilizing the heated water to preheat ventilation air during those time when the heat-storage temperature is too low to make use of the heat in the in-floor radiant heating system.

PERFORMANCE DATA

Solar System Efficiency Levels: Winter, 16%
Summer, 25%

Collector Size: 1,050 ft^2 Solar System Cost: $ 9,637.50

Assumptions

1. Utilize all of the Btu that are collected
2. L.P. gas as an average conventional fuel source provides 73,600 Btu/gal
3. On a south-facing 45° sloped roof, approximately 228,000 Btu/ft^2 are available from October through March (Winter)
4. On a south-facing 45° sloped roof, approximately 348,000 Btu/ft^2 are available from April through September (Summer)
5. 1 gallon of L.P. gas costs $0.60

Payback Calculation

Winter; October - March

$$\frac{228{,}000 \text{ Btu}}{\text{ft}^2} \times .16 \times 1{,}050 \text{ ft}^2 \times \frac{1 \text{ gal L.P.}}{73{,}600 \text{ Btu}} = 520 \text{ gal. L.P. gas}$$

Summer; April - September

$$\frac{348{,}000 \text{ Btu}}{\text{ft}^2} \times .25 \times 1{,}050 \text{ ft}^2 \times \frac{1 \text{ gal L.P.}}{73{,}600 \text{ Btu}} = 1{,}241 \text{ gal. L.P. gas}$$

520 gal L.P. + 1,241 gal L.P. = 1,761 gal L.P. gas

1,761 gal L.P. x \$0.60/gal L.P. = \$1,056.60

$$\frac{\$9{,}637.50}{\$1{,}056.60} = 9.1 \text{ or } 9 \text{ years until payback}$$

General Recommendations for Utilizing Solar Heat for Livestock Production

GENERAL

Be sure to insulate the building you plan to heat before spending money on a solar energy system.

Whenever possible, make multiple use of the solar system. For instance, a solar attic in a livestock building may be used to preheat air for drying grain and can also be used to preheat livestock ventilation air. Grain drying occurs in the Fall and will not greatly interfere with the use of solar energy for heating livestock. This dual use will greatly increase the return from the solar investment.

Solar collectors for preheating outdoor air can be both simple and efficient when made as part of the structure, they add $1.00 to $3.00 per square foot of collector to the cost of conventional construction.

The amount of energy collected by a 4/12 sloped solar roof collector which operates at 15 percent efficiency is worth $0.25 per square foot of collecter per heating season from October through March, allowing $0.60 per gallon for L.P. gas.

At the above rate, a roof collector that adds $1.50 per square foot to the overall building cost will require about 6 years to recover the investment.

For collectors for heating livestock ventilation air, provide a minimum of 1 square foot of collector area for every 1 to 4 cubic feet per minute (cfm) of ventilation air.

LOCATION

When possible position the collector so that it faces south along an east-west axis. However, facing 15 to 20 degrees away from due south is not serious. If a roof collector must be oriented along a north-south axis, use both the east and west sides of the roof as a collector. The total solar energy collected using both the east and west sides of the roof as compared to using only the south roof of an equal-sized building is about the same. There would be an increased cost for the extra fiberglass.

The most efficient slope for a solar collector during the winter can be found by adding 15 degrees to the location's latitude. This method would give a collection angle of 52 degrees in southern Illinois and 57 degrees in northern Illinois. For year-round heating, use the degrees of latitude for the angle. For example, at 40 degrees latitude, use a collector angle of 40 degrees.

Avoid placing a collector behind objects that could block the sunlight. Remember, small trees soon grow large and can shade a collector. Noon shadows extend horizontally a distance of twice the height of the object in winter.

CONSTRUCTION

Use clear, greenhouse grade fiberglass with a coating to protect the cover from ultraviolet light. A 15-year written warranty for greenhouse use is a good indication of quality. However, most companies today will not guarantee the fiberglass for solar-collector use because no one knows what collector temperatures might be reached or whether those higher temperatures will cause the fiberglass to deteriorate more rapidly.

To install the fiberglass, it is a good idea to use hex-head, self-tapping screws with rubber gaskets to fasten it to the collector or roof. Using the screws will be helpful if you have to take off a sheet of fiberglass for any reason. Pre-drill all holes through the fiberglass 1/32-inch larger than the screws or nails to avoid shattering the fiberglass.

Seal the collector against air leaks. Silicon caulking is a good caulking agent. One tube will cover approximately 75 to 100 linear feet. It is recommended that a small amount of caulking be used around every nail or screw hole to assure proper sealing.

Screen the air inlets into the collector to make them rodent-proof and locate them so snow will not blow into or drift over them.

Remember that dust on the interior surface of the fiberglass cover can not be reached for cleaning and will reduce light transmission, so plan air inlet location to reduce the dust intake.

Use a black absorption surface to collect the solar energy. You can spray almost any material with flat black paint. Metal surfaces may need to be primed. See the paint manufacturer's instructions.

Avoid large pressure drops by alowing 1 square foot of duct cross section area for every 500 to 600 cubic feet per minute (cfm) of air movement. This will result in a maximum velocity of 500 to 600 feet per minute. The maximum velocity for grain drying can be increased to 1,000 feet per minute.

Keep the total air-flow resistance below a static pressure of 1/2 inch of water--1/4 inch is better. Greater static pressure reduces fan performance.

Insulate the back and sides of the collector to conserve heat. Use batt or polyurethane insulation. Don't use polystyrene because manufacturers don't recommend its use at temperatures higher than 165 degrees.

Plan to ventilate the collector during summer when it's not in use either by providing openings that will allow air to flow through the collector or by installing a fan to move air through the collector. The stagnation of air in a collector can result in temperatures of more than 200 degrees inside the collector. Extended exposure to temperatures above 200 degrees may damage the

fiberglass and the structural members of the building. A vented area of 1 percent of collector area is suggested for warm air outlets and the same amount for inlets.

ATTIC COLLECTOR

If an attic collector is oriented with an east-west axis, partition off the south half and use only this portion of the attic. Insulate between the south and the north portions of the attic.

It is important to vent solar attics to keep temperatures below 200°F in summer. Provide an equal amount of openings both at the eave and at the ridge to allow air to flow through the attic. Ridge venting can be provided with both ridge vents and louvers in the gable ends. Thermostatically controlled fans can also be provided to assure adequate venting. If a fan is used, seal the fan off during winter.

Reduce the moisture problems in solar attics by preventing backdrafts. One solution would be to reduce the chimney duct area during periods of low volume ventilation to maintain uniform air velocity. Another, would be to install a backdraft shutter. A weighted plastic curtain that allows air to flow in only one direction works satisfactorily.

ROCK HEAT STORAGE

When planning for a rock heat storage, the rock volume should be about 1 cubic foot of rock for each cubic foot per minute of air flow required for the livestock ventilation system.

Because there are typically only 6 to 8 hours of sunshine per day and the rocks must be charged with heat in about one-third to one-fourth of the 24-hour day, the capacity of the charging fan should be three to four times as much as the ventilation fan pulling air from the rock storage. Fan capacities should be based on delivery against 1/4-inch static pressure.

It is important to use uniformly sized rocks.

Insulate the sidewalls and underneath the rock heat storage.

If the rocks used in the heat storage are to be located underground, do not go below the water table level and provide drainage if needed.

Select rock size to limit the static pressure resulting from the charging fan to 1/4 inch. The rock sizes may vary from 1 to 4 inches.

During a day when the outside midday temperature rises 30 to 50 degrees above the nighttime temperature, the midday temperature of the ventilation air coming from the rock storage can be lower than the outside air temperature. This can be corrected by installing a differential thermostat that controls the discharge fan from the heat sotrage and a motorized shutter that allows outside air to enter the building when it is warmer than the air from the solar heat storage.

HOT WATER COLLECTOR

When using a water collector, be sure the water can drain down completely when the system isn't operating. If water is left in the collector, it will freeze, bursting the pipes.

The overall efficiency of a water collector can be improved if some heated water is used to help heat the ventilation air. When the hot water is used only for an in-floor radiant heating system, the solar heated water must reach 110°F or higher before it is effective.

Insulate the water storage tank, the pipes carrying the water, and under the collector absorber plates.

Purchase the solar panels from a reputable dealer. Examine the dealer's service policy and past service performance.

Publications and Educational Activities

PUBLICATIONS

1. Rahn, C. L. 1980. Solar livestock building demonstrations. In: Proceedings of Farm Structures Day (March 13, 1980). Dept. of Agr. Eng., College of Agr., Univ. of Ill. at Urbana-Champaign. 4 p.

2. Muehling, Art. 1980. Solar heats hogs and dries grain. Ag. Energy, Vol. 1, No. 2. Miller Publ. Co., Minneapolis, MN.

3. Rahn, Chris, and Arthur J. Muehling. 1980. Consider solar heat for livestock units. Prairie Farmer. Vol. 152, No. 18. pp. 80-81.

4. Rahn, Christopher. 1981. Lean-to solar collector helps heat hog building. Prairie Farmer. Vol. 153, No. 18, pp. F-12 α F-13.

5. Rahn, Christopher, L., and A. J. Muehling. 1981. Solar heating ventilation air in a swine farrowing and nursery building. Energy Tips No. 3. Dept. of Agr. Eng., College of Agr., Univ. of Ill. at Urbana-Champaign. 4 p.

6. Peterson, William H., and Christopher L. Rahn. 1981. A lean-to collector and heat storage system for heating ventilation air in livestock buildings. Energy Tips No. 5. Dept. of Agr. Engr., College of Agr., Univ. of Ill. at Urbana-Champaign. 8 p.

7. Rahn, C. L., and A. J. Muehling. 1982. Solar collector for heating ventilation air in livestock housing. Paper presented at 2nd International Livestock Environment Symposim, Ames, Iowa. 5 p.

8. Peterson, William H., and Christopher L. Rahn. 1982. A solar collector with rock storage for heating livestock ventilation air. ASAE paper 82-4044, presented at Summer Meeting of ASAE (June 27-30, 1982), Madison, WI. 11 p.

9. Rahn, Chris, and Art Muehling. 1982. Preplan solar collector building project. Prairie Farmer. Vol. 154, No. 14. p. 36.

VIDEOTAPES

1. Solar heating for livestock buildings. 1982. 18-minute videotape. College of Agr., Univ. of Ill. at Urbana-Champaign. (Awarded blue ribbon at Educational Aids Competition, American Society of Agricultural Engineers Annual Meeting, Madison, WI).

PLANS

1. Illinois plan no. 572. 1982. Lean-to solar collector with rock storage. Dept. of Agr. Eng., Univ. of Ill. at Urbana-Champaign. 3 sheets.

2. Illinois plan no. 573. 1982. 600-sow solar heated swine production unit. Dept. of Agr. Eng., Univ. of Ill. at Urbana-Champaign. 15 sheets.

3. Illinois plan no. 574. 1982. 200-sow solar heated swine production unit. Dept. of Agr. Eng., Univ. of Ill. at Urbana-Champaign. 11 sheets.

INFORMATION MEETINGS

1981 Meetings

14 solar workshops for producers -- 715 attending
7 solar tours -- 500 attending

1982 Meetings

8 producer solar workshops -- 250 attending
4 farm builder solar workshops -- 145 attending
33 swine seminars -- 1150 attending
Illinois Farm Structures Day -- 125 attending

Iowa Demonstration Of Solar Heat For Livestock Facilities

FINAL REPORT

Vernon M. Meyer, William F. Wilcke, Extension Ag. Eng., ISU, Ames, IA

This is the final report of a project demonstrating on-farm use of solar heat in livestock buildings. The project was conducted by Iowa State University Cooperative Extension Service in cooperation with the U.S. Department of Agriculture's Science and Education Administration. Funding was by the U.S. Department of Energy and data was collected by Iowa State University Extension Agricultural Engineers.

PROJECT GOALS

For Iowa, the greatest space heating need in livestock production is in swine nurseries and farrowing houses, so all of our demonstration facilities were solar swine buildings. One swine producer was selected from each of the 12 extension areas in Iowa to cooperate in the project. Plans fell through in one area, so we were left with 11 cooperators at the locations shown in Figure 1. Five goals were developed for working with the cooperating farmers.

1. Demonstrate the technical and economic feasibility of using existing solar energy technology to provide significant amounts of the heating requirements for on-the-farm farrowing and nursery buildings.

2. Test to the maximum extent possible solar energy technology developed under the federal research program under typical farm conditions.

3. Incorporate and utilize energy conservation techniques well-known to the industry but not always used in commercial solar buildings.

4. Conduct the demonstration activities with minimum interruption or interference in the normal operation of the livestock facility.

5. Identify possible multiple uses of the solar collector for grain drying prior to the winter heating season in the swine facility.

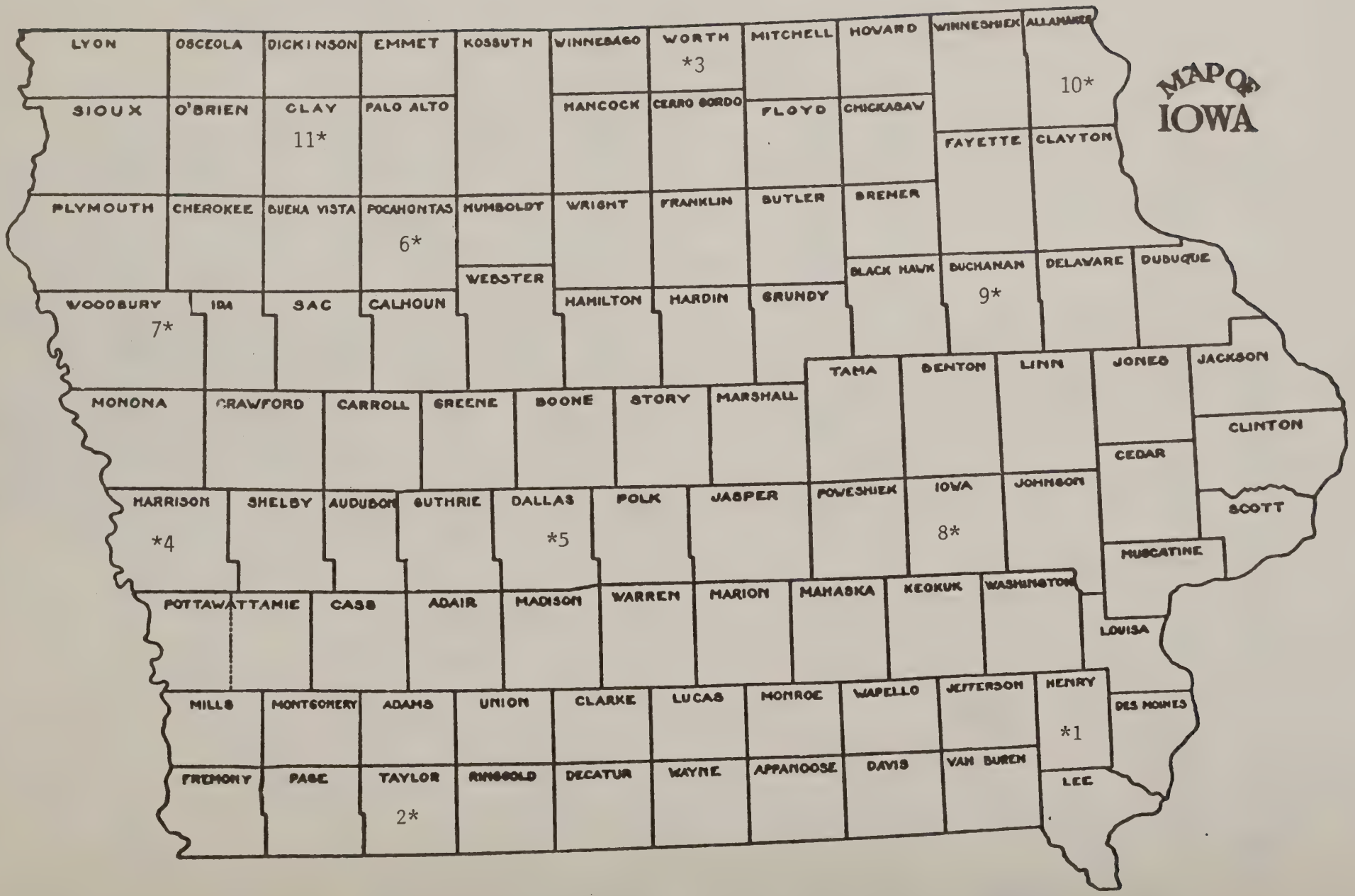


Figure 1. Location of Cooperators in Iowa's Solar Demonstration Project

COLLECTOR TYPES

A brief description of each collector is presented in Table 1. All 11 collectors were single-channel, single-cover collectors using clear greenhouse-grade fiberglass reinforced plastic (FRP) glazing. They were all used to preheat winter ventilating air and were all site-built by the cooperators or local contractors.

Seven of the collectors were south-wall units (90° tilt angle), two were built into roofs, one was built on sloping ground next to the building, and one was a portable unit with adjustable tilt angle. Five of the systems used heat storage. In each case, the heat storage material was black-painted concrete which also served as the collector absorber.

COLLECTOR MONITORING

Our original goal was to collect about one month of data on each collector for each of three winters. Unfortunately, the following factors prevented us from reaching that goal (see Days of Good Data column in Table 2):

* Early termination of the demonstration project.
* Delays in obtaining equipment.
* Numerous power outages. Each outage put the data acquisition system out of commission until someone reloaded the program.
* Rodent damage to wires.
* Noise susceptibility of the data acquisition system.
* In two cases, the cooperator was not using the solar swine facility when we had equipment available to monitor it.

We used three PET Data Acquisition Systems (PDAS) to monitor our collectors. PDAS was designed by two Iowa State University computer engineering students and included an ordinary 32k Commodore PET microcomputer interfaced with an analog-to-digital conversion (ADC) board. We designed signal conditioning circuits to change sensor signals to the 0 to 5VDC required by the ADC board.

We used Analog Devices, Inc. AD590H integrated circuits to measure temperatures. Sensors were normally installed to measure ambient air temperature (in a shaded spot near the collector inlet), collector outlet temperature (at several points), and room temperature. LiCor, Inc. Li-200s pyranometers were fastened to the collector cover, at the collector tilt angle, to measure incident solar radiation. In buildings with constant speed fans, a J-Tec Associates, Inc. hand-held anemometer was used to find fan airflow and then a relay connected to the fan motor terminals, or a Kurz Instruments, Inc. hot-wire anemometer with 0-5VDC electrical output was used to indicate when the fan was on. In buildings with variable speed fans, instantaneous airflow was calculated using instantaneous velocity readings from a Kurz hot-wire anemometer mounted in a duct somewhere in the solar heating system.

Table 1. Description of solar collectors in Iowa's demonstration project

Cooperator	Size (ft^2)	Tilt Angle	Cover	Absorber	Storage	Airflow (cfm/ft^2)
1. Howard Dutton Mt. Pleasant	200	Adjustable	Corrugated FRP	Black-painted aluminum	None	5
2. Keith Farrens Bedford	762	90°	Corrugated FRP	Black-painted concrete	8" poured concrete wall	Variable
3. Truman Hengesteg Northwood	112*	90°	Ribbed FRP	Black-painted 3/8" siding	None	6
4. Leonard Hoffman Missouri Valley	136	56°	Corrugated FRP	Black-painted plywood	None	12 (1.8 avg) (fan only on 1½ min/10)
5. Jim & Clarence Keller Dallas Center	420	90°	Corrugated FRP	Black-painted concrete blocks	Concrete block wall - all cores concrete-filled	2.9
6. Kerns Ag. Co. Farm Rolfe	988	38°	Corrugated FRP	Black-painted sheathing boards	None	0.4
7. Larry Knaack Correctionville	576 1152	35° 16.5°	Corrugated FRP	Black-painted concrete blocks	Concrete blocks	0.7
8. Jerald McCaw Williamsburg	480	90°	Corrugated FRP	Black-painted concrete blocks	Concrete block wall	2.0
9. Murley Farms, Inc. Aurora	330	90°	Flat FRP	Black-painted plywood	None	1.3
10. James & Dave Prestemon Waukon	480	90°	Flat FRP	Black-painted concrete blocks	Concrete block wall ½ cores sand- or gravel-filled	1.0
11. Larry Wilson Moneta	552	90°	Corrugated FRP	Dark-green corrugated metal siding	None	1-6

*Only part of the collector was monitored; total collector area equals 420 ft^2

Table 2. Performance of solar collectors in Iowa's demonstration project

Table 2. Performance of solar collectors in Iowa's demonstration project

Cooperator	Efficiency (%)	Fuel Savings (gal LP/ft^2·yr)	Collector Cost ($/ft^2)	Merit Figure (Cost/Savings)	Days of Good Data	Comments
Dutton	----- Not Monitored -------		5.50	--	0	-Portable collector. Had intended to use collector for grain drying and space heating, but found that he can dry grain without supplemental heat.
Farrens	----- Not Monitored -------		6.67	--	0	
Hengesteg	60	1.59	4.35	2.74	2	-Not much data due to power outages. High efficiency probably result of high airflow.
Hoffman	18	0.54	7.08	13.11	23	-Low collector efficiency caused by intermittent fan operation.
Keller	56	1.47	15.00	10.20	14	-Good performance, but high first cost.
Kerns	16	0.46	2.90	6.30	14	-Forced convection past absorber would improve efficiency. Similar efficiency found for similar collectors in Illinois.
Knaack	23	0.61	2.78	4.56	8	-Has some problems with snow accumulation on collector cover.
McCaw	40	1.05	5.26	5.01	23	-Reasonable cost and performance.
Murley	33	0.88	4.35	4.94	14	-Had to replace polystyrene insulation behind absorber with fiberglass.
Prestemon	24	0.62	5.71	9.21	3	-Not much data due to problems with monitoring equipment. Leaking sand caused some airflow restriction in the collector.
Wilson	36	0.95	1.71	1.80	13	-High airflow leads to reasonable performance in even low-cost collectors; results in good merit figure.

The first step in monitoring the collectors was to find out when the solar facility was going to be at least half-full for a one month time period, set up an installation date, and arrange for a spot to set the PDAS. Then, an Extension Ag Engineer from Ames would haul the monitoring equipment to the cooperator's farm, install the PDAS in a plywood box with plexiglass front inside the swine building or storage room near it, install and calibrate the sensors, program the PET, save the program on cassette tape, install a blank data tape, and start data collection. In some cases, the cooperator or local extension personnel helped install the equipment and learned how to reload the program. One side of a 90-minute cassette tape should have provided ample storage for one month's data, but we usually changed the tape every time we visited the farm to check or troubleshoot the monitoring equipment.

During data collection, all the sensors were sampled and the PET video display was updated every minute. The display included time, ambient temperature, collector temperature rise, instantaneous solar input, and instantaneous collector heat output. The cooperators liked the video display and found it to be educational. It also helped us in troubleshooting the solar and data acquisition systems. If something on the display didn't make sense, the cooperators could call to let us know. We tried to use the screen display as part of an outdoor (visitors were not allowed inside the swine building because of disease concerns), afternoon field day, but found it hard to read in sunlight.

Although sensors were sampled every minute, data were recorded on cassette tape only once per hour. The data included: time; date; instantaneous temperatures, solar input, collector heat output, and airflow; solar insolation and collector heat out integrated over the last hour; total solar input and collector heat output since the PET was programmed.

DATA ANALYSIS

Data tapes were returned to the Ag Engineering Department where another PET and printer were used to analyze and make a printed copy of the data. Ambient and collector output temperatures were graphed, data corrected where necessary, and efficiencies, fuel savings, and merit figures were calculated.

$$\text{Efficiency} = \frac{\text{Collector heat output during monitoring period}}{\text{Solar input during monitoring period}}$$

$$\text{Fuel Savings} = \frac{\text{Efficiency x Avg. solar available Oct. through March}}{\text{Energy from 1 gal LPG (=0.9 x 92,000 Btu/gal)}}$$

It was assumed that the solar collector would be used continuously during an October through March heating season and that the collector efficiency measured during the monitoring period equalled the season average. Many of our cooperators farrow continuously and would need to heat buildings October through March in an average year. Average solar energy values used in the equation are from "Introduction to Solar Heating and Cooling: Design and Sizing, U.S. DOE/CS-0011" for Ames, IA, for the published tilt angle closest to that of each collector.

We used 90% burner efficiency in the equation because all of our cooperators use unvented LPG or natural gas heaters to provide backup heat.

$$\text{Merit Figure} = \frac{\text{Solar collector first cost (\$/ft}^2\text{)}}{\text{Projected fuel savings (gal LPG/ft}^2\text{ yr.)}}$$

The merit figure is a very crude cost/benefit number that allows ranking the collectors. Collectors with low merit figures should pay for themselves fastest.

COLLECTOR PERFORMANCE

Cost and performance of the collectors is summarized in Table 2. Efficiencies ranged from 16% to 60%. It seemed that the match between airflow and collector size (cfm/ft^2) was the primary determinant of collector efficiency. High airflows increase heat transfer coefficients and reduce heat losses and so produce high efficiencies. If the collectors are listed in order of decreasing efficiency, collector airflow (from Table 1) decreases in about the same order.

There was really no correlation between collector first cost and collector performance. To have a low merit figure, a collector must have a low first cost and be operated at a high airflow so that it has a reasonable efficiency and fuel savings.

DEMONSTRATION ACTIVITIES

The following activities were undertaken by Extension Agricultural Engineers to disseminate information on the demonstration project.

* A 77-slide, 26-minute slide/tape set was developed (Solar Heat for Swine Facilities: Iowa's Demonstration Project). The set contains basic information on solar energy, describes the project, presents information on each cooperator's collector, and gives recommendations to farmers considering solar ventilating-air preheaters. One copy of the set will be available from Media Resources on the ISU campus, two from Ag. Eng. Extension, and one from each of the 12 extension area offices.

* A paper was presented at and will appear in the proceedings of the Iowa Solar Operational Results Conference held at Hotel Fort Des Moines, Des Moines, IA, June 21-22, 1982. The title was Solar Heat for Livestock Facilities: Iowa's Demonstration Project by William F. Wilcke and Vernon M. Meyer.

* A field day was held at the farm of cooperators Jim and Clarence Keller on September 22, 1980. Jim and Clarence, the county extension director, and two extension ag engineers were on hand to give short presentations, answer questions, and demonstrate the data acquisition equipment.

Attendance was good, but problems with seeing the slides and video display and concern about spreading swine diseases led to a decision to hold no more field days.

* A series of Cooperative Extension bulletins, Pm-979a through 1 was developed and made available through ISU Publications Distribution and extension offices. Pm 979a gives a project overview and each of the others is a one page fact sheet describing one cooperator's collector and farming operation.

* Another set of follow-up bulletins describing each collector and its performance (without the cooperators name and address) is planned.

* About 93 presentations on solar heat for livestock buildings and the demonstration project have been made by Extension Ag Engineers since the project began and another 12 are planned for the coming program year.

* Two identical stand-alone displays describing solar heat for livestock buildings have been developed and made available for use at fairs, meetings, and energy events.

* An Apple III microcomputer is being used to model swine buildings with solar ventilating-air preheat in an effort to evaluate the economic worth of the solar preheat.

RECOMMENDATIONS

Based on information obtained from the demonstration project, we recommend that farmers considering solar ventilating-air preheaters:

* Limit collector size to 0.3 to 0.5 ft^2 per cfm of ventilating air (2 to 3 cfm per ft^2 of collector).

* Make the building as airtight as possible so that all winter ventilating air passes through the collector. And carefully seal the collector and air ducts to prevent efficiency-robbing air leaks.

* Provide alternative air inlets to the building (preferably with automatic controls), so that the solar collector can be bypassed on warm days.

* Vent, cover, or shade the collector in summer to keep it cool. This should increase collector life and reduce building cooling load.

* DO NOT use polystyrene insulation in a solar collector.

* Try to keep collector first cost under about \$7/ft^2 (1982).

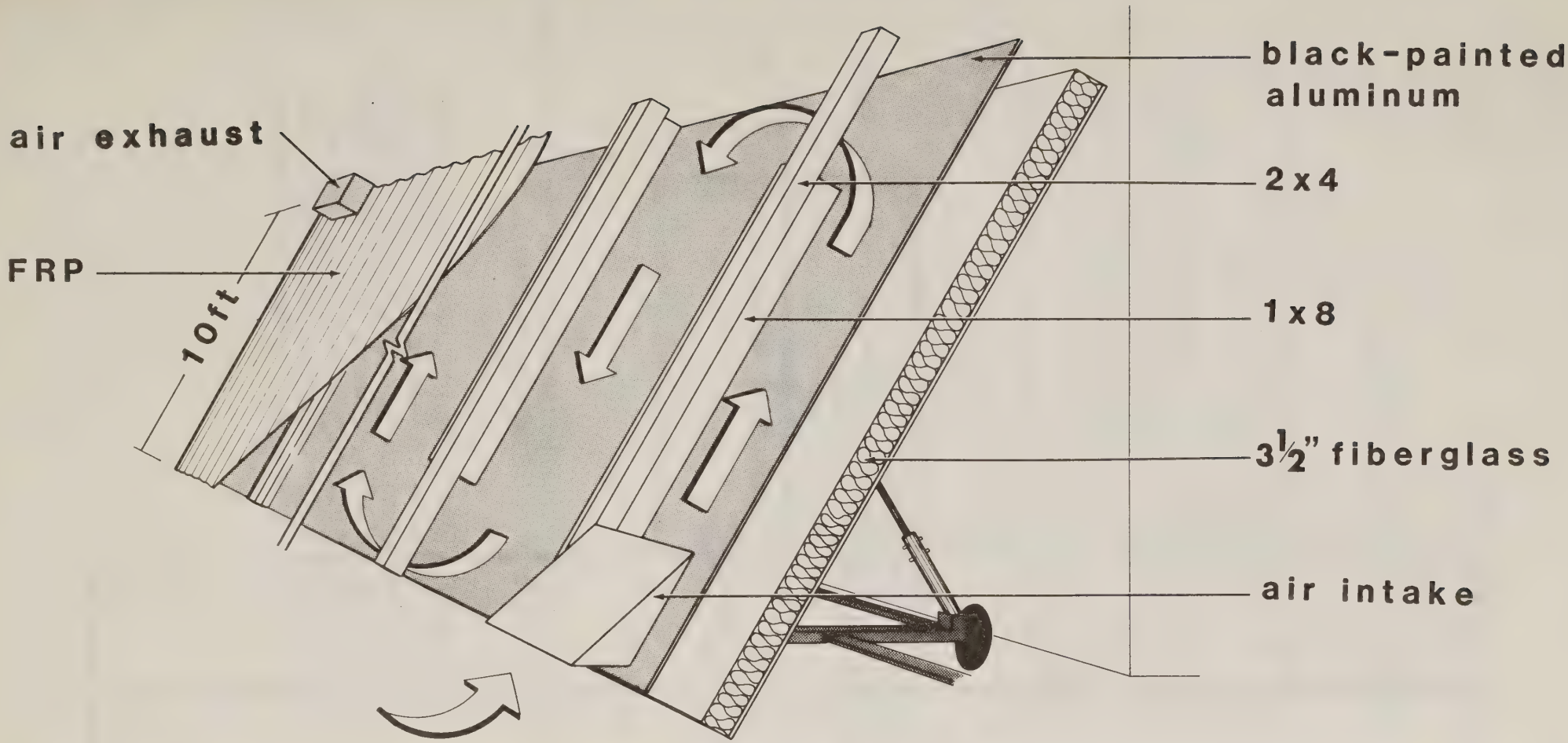
We feel that if farmers follow these recommendations, their solar collectors should save money as well as energy.

SYSTEM DESCRIPTIONS

The following section describes each cooperator's farming operation and solar facility, presents solar cost and performance information, and includes plan views and schematics of the solar facilities.

COLLECTOR NO. 1

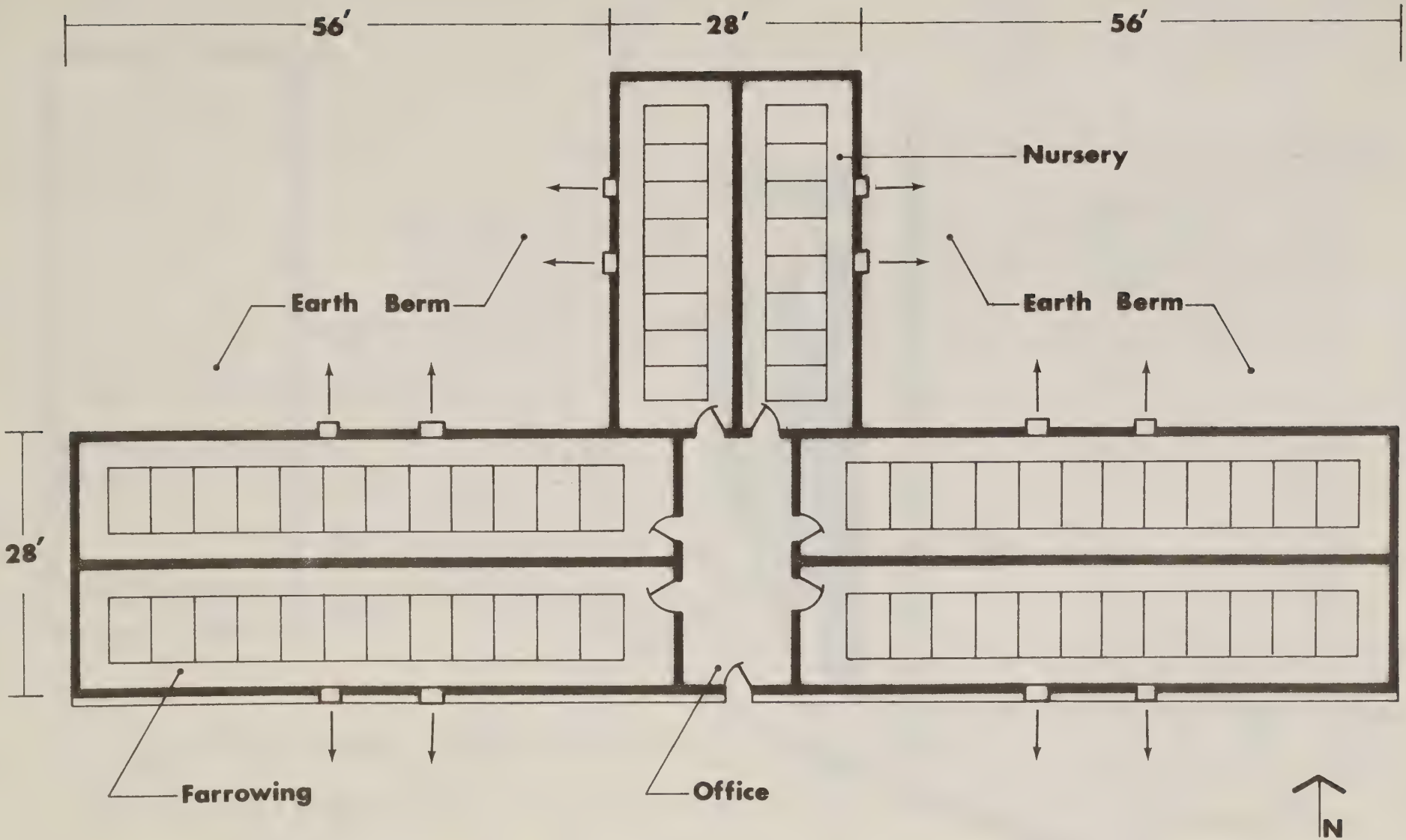
THE FARM	Howard Dutton Farm, Mt. Pleasant 100 acres, cattle, 1000 hogs/yr.
SOLAR BUILDING	Older 22 x 50 farrowing and nursery unit 21 farrowing crates, 8 used for nursery area 7' deep manure pit under floor Pigs weaned and moved to nursery area at 3-5 weeks, removed from building at 60 lbs. Insulation: ½" urethane in walls and ceiling, plans to add more 75,000 Btu/h LPG heater plus heat lamps and electric floor heat
COLLECTOR DESCRIPTION	10 x 20, 200-ft^2 portable collector Built from hull of old houseboat and running gear in 1978 Corrugated FRP cover Black-painted aluminum absorber Serpentine air channel formed by wood 1 x 8s No heat storage Telescoping support pipes make tilt angle adjustable Fan mounted on upper left corner of collector draws ambient air through the collector and pushes it into the building. Airflow: 5cfm/ft^2
COST	About \$5.50/ft^2
PERFORMANCE	Not measured yet, was concerned about disease problems and was not using collector when monitoring equipment was available.
COMMENTS	Had intended to use collector for both grain drying and heating swine building - found that supplemental heat was not needed for grain drying (just uses natural air)


air exhaust
FRP
10ft
black-painted aluminum
2x4
1x8
3½" fiberglass
air intake

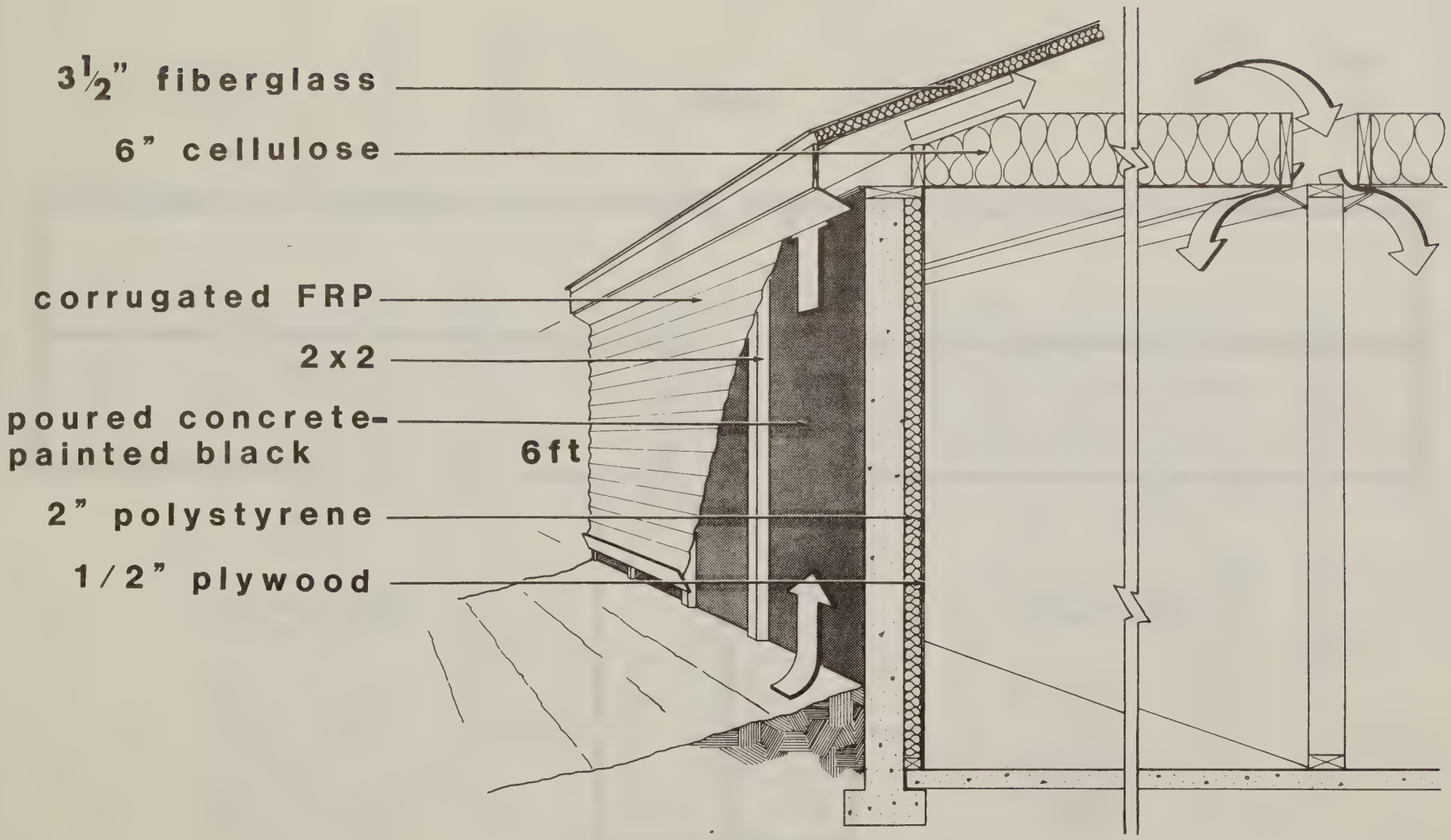
DUTTON FARM

COLLECTOR NO. 2

THE FARM	Farrens Farms, Inc., Bedford 500 acres, cattle, 3200 hogs/yr.
SOLAR BUILDING	T-shaped building earth bermed to the eave on the east, west, and north sides; built in 1979 Four 14 x 64, 12-sow farrowing rooms Two 14 x 36 nursery rooms Gravity drain gutters are used to remove waste Pigs are weaned and moved to nursery at 4-5 weeks and removed from building at 40 to 50 lbs. Insulation: 2" polystyrene in walls, 6" cellulose in ceiling, 3½" fiberglass between rafters 175,000 Btu/h LPG heater Each room has its own exhaust fans; nursery fans are variable speed
COLLECTOR DESCRIPTION	6 x 127, 762-ft^2 south wall collector Corrugated FRP cover 8" thick, black-painted, poured concrete wall serves as absorber and heat storage Vertical wood 2 x 2's form air channels on wall Air enters screened inlet at base of wall, up past concrete, into insulated air space in attic, and from there into rooms Airflow: variable
COST	$6.67/$ft^2$
PERFORMANCE	Not measured yet, collector was not in use in early March when monitoring equipment was available.
COMMENTS	Cooperator decided to bypass the collector during his March farrowing because he didn't want to be bothered with managing the collector when planting time arrived. (Collector must be bypassed on warm days to prevent building overheating.) Automatic controls would allow use of collector spring and fall, without increasing management requirements.



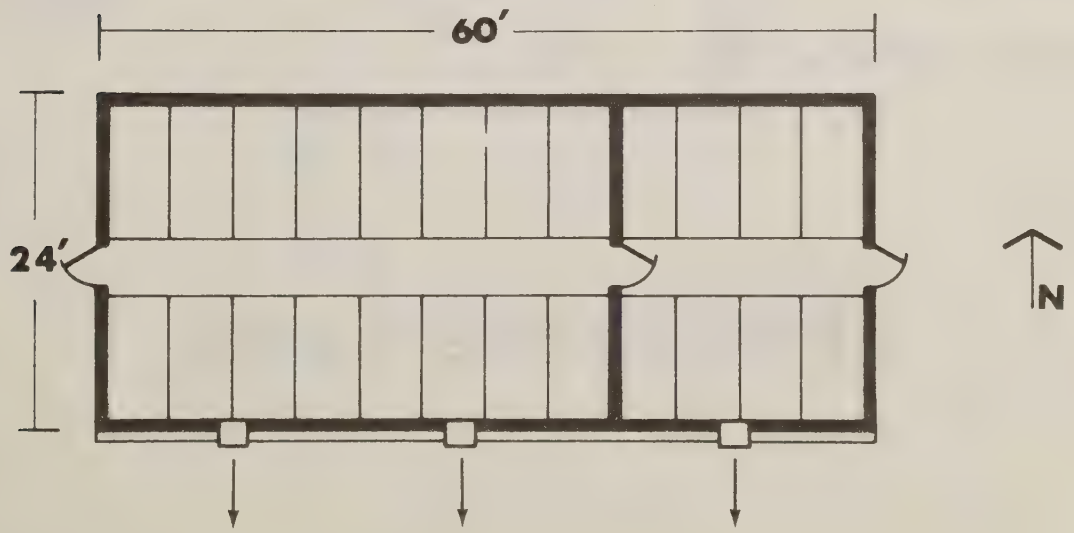
Farrens solar farrowing house and nursery

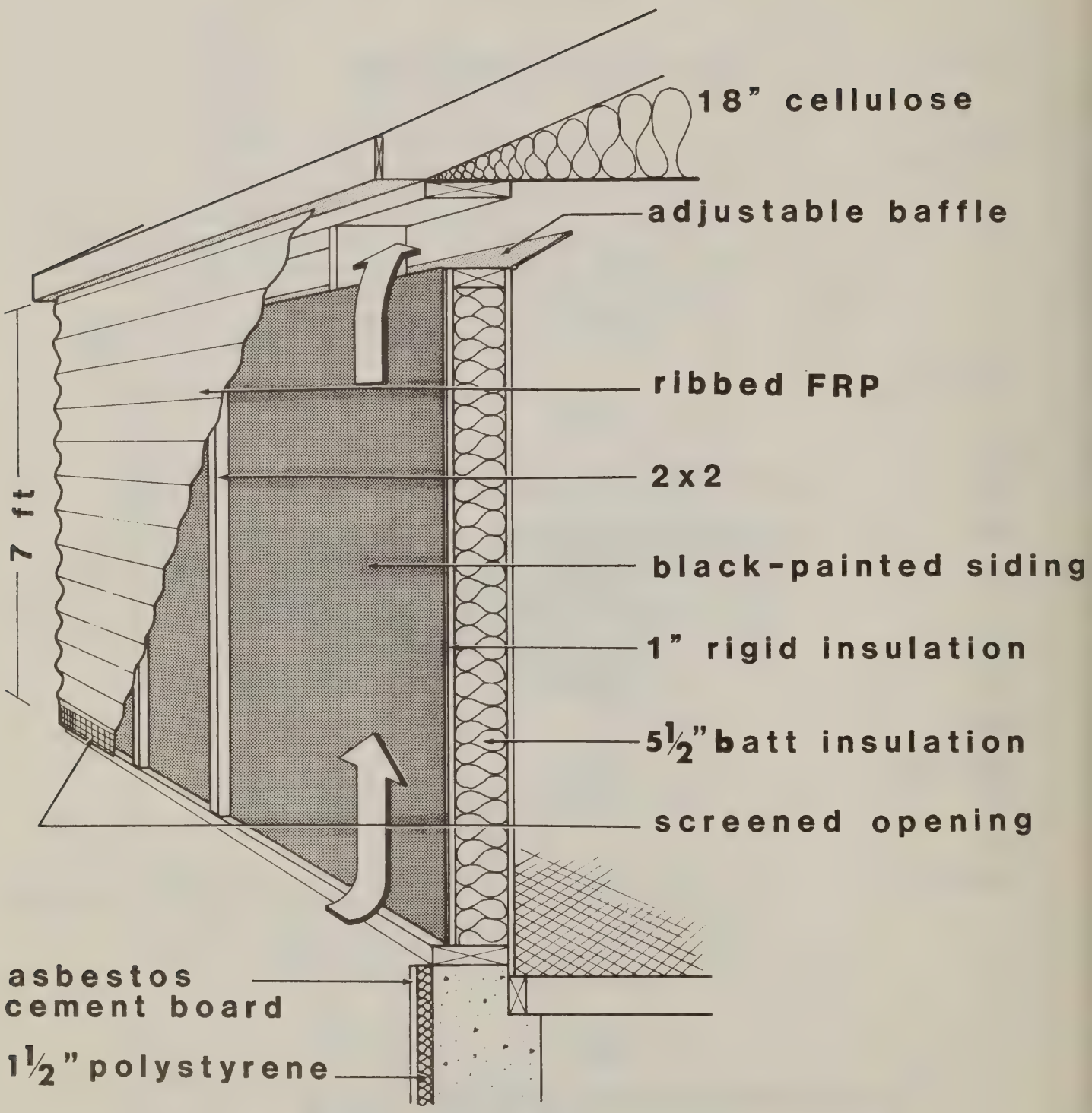


FARRENS FARM

COLLECTOR NO. 3

THE FARM	Truman Hengesteg Farm, Northwood 1300 acres, cattle, 2200 hogs/yr.
SOLAR BUILDING	24 x 60, 24-pen swine nursery, built in 1979 Two rooms, east end for smallest pigs Plastic-coated, expanded metal floor over 8'pit Insulation: 5½" fiberglass plus 1" polystyrene in walls, 18" cellulose in ceiling, 1½" polystyrene around perimeter Pigs moved in at 3 weeks, later moved to finishing barns 60,000 Btu/h LPG heaters are available Variable speed pit fans provide ventilation; hinged inlet baffle is adjusted morning and night at choretime
COLLECTOR DESCRIPTION	7 x 60 vertical collector incorporated into south wall of building Cover material is ribbed FRP Absorber is black-painted hardboard siding Air channels formed by vertical wood 1½ x 2 strips No heat storage Outside air enters screened inlet at base of collector, moves up between siding and FRP, passes through opening at top of stud-frame wall, and is deflected along ceiling by hinged baffle; pit fan pulls air down through floor and exhausts it from building Airflow: about 6 cfm/ft^2 during monitoring period
COST	\$4.35/ft^2
PERFORMANCE	60% efficiency 1.59 gal LPG/ft^2·yr projected fuel savings No backup heat was used in the building winter 1981-1982
COMMENTS	The relatively high efficiency of this collector probably results from the high airflow through the collector. Only the east end of the collector was monitored (112 ft^2) because the west end was not in use yet when monitoring began in November 1981.

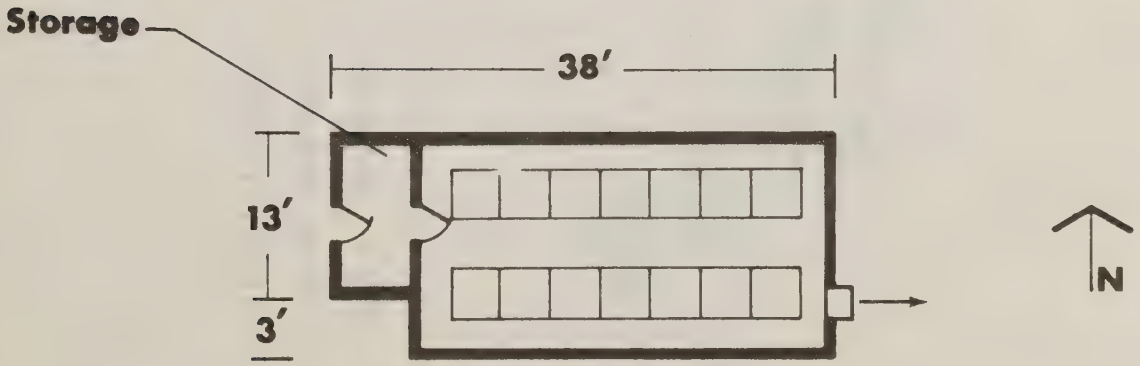




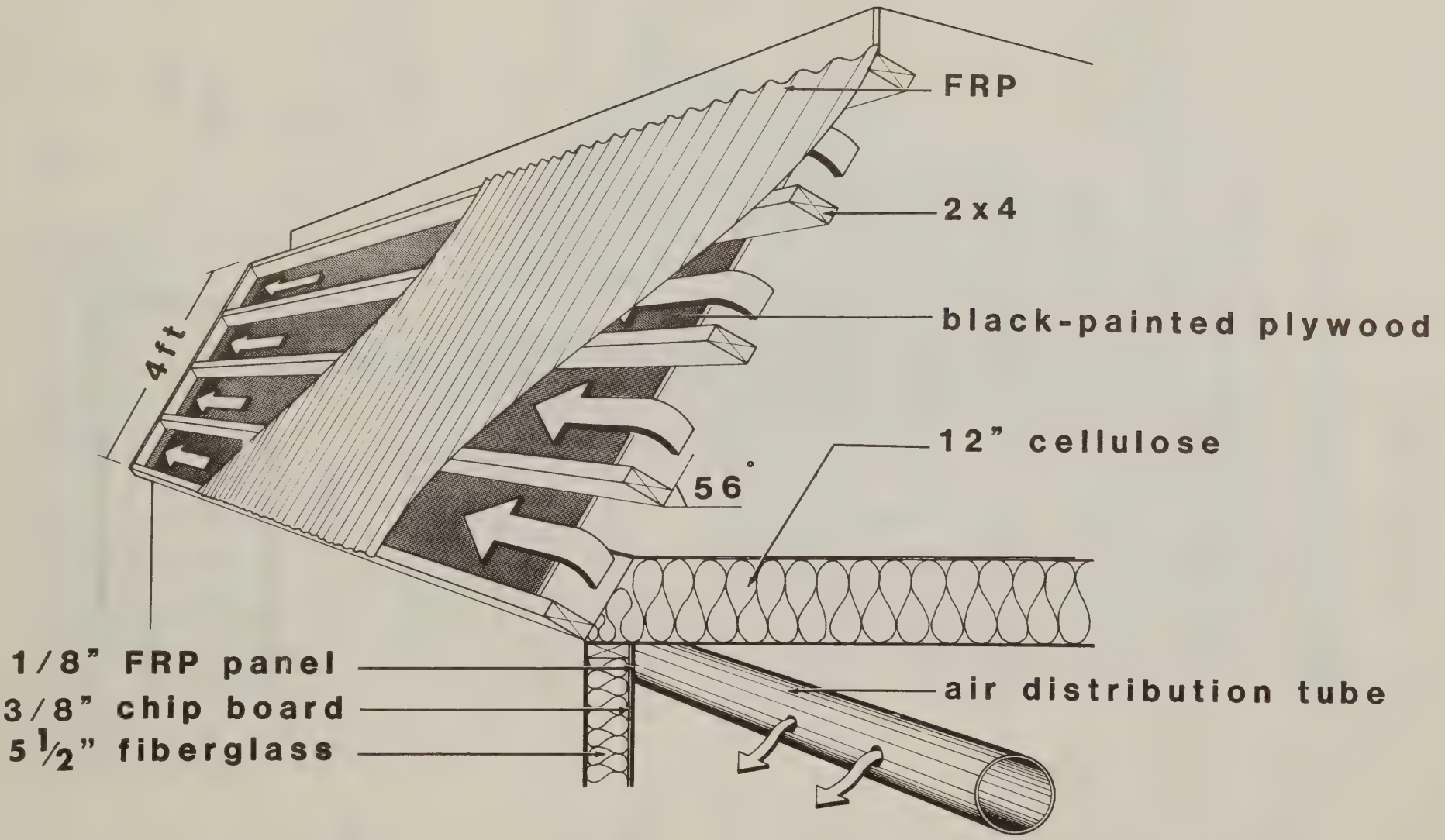
HENGESTEG FARM

COLLECTOR NO. 4

THE FARM	Leonard Hoffman Farm, Missouri Valley 312 acres, 900 hogs/yr.
SOLAR	16 x 32, 120-pig nursery, built in 1979 14 raised pens with mesh floors, waste removed through flush gutters Pigs brought in at 15-20 lbs, out at 40-50 lbs 12" cellulose ceiling insulation, 5½" fiberglass in sidewalls 60,000 Btu/h LPG heater Winter ventilation: 1600 cfm fan on timer; adjusted to provide about 2 cfm/pig
COLLECTOR DESCRIPTION	Built into roof, 56° tilt angle 4 x 34, 136 ft^2 Corrugated FRP cover Black-painted plywood absorber Air channels formed by horizontal 2 x 4s No heat storage Air enters east end of collector from attic, moves past absorber to duct on west end, enters building through damper, distributed by fan on inflatable plastic tube, exhausted by fan in southeast corner of building. Airflow: 12 cfm/ft^2 when fan on, 1.8 cfm/ft^2 avg.
COST	\$7.08/ft^2
PERFORMANCE	18% efficiency 0.54 gal LPG/ft^2.yr projected fuel savings
COMMENTS	Collector performance could be greatly improved by using a small continuous ventilation fan instead of a large intermittent one.



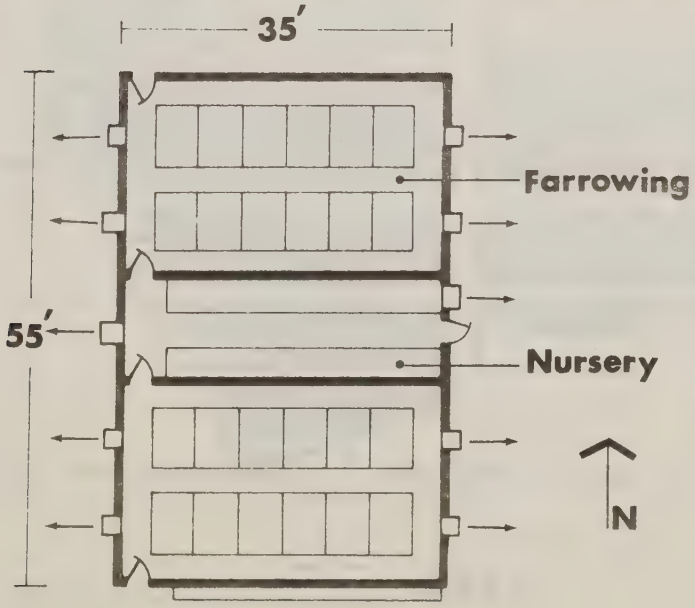
Swine nursery with solar collector built into roof

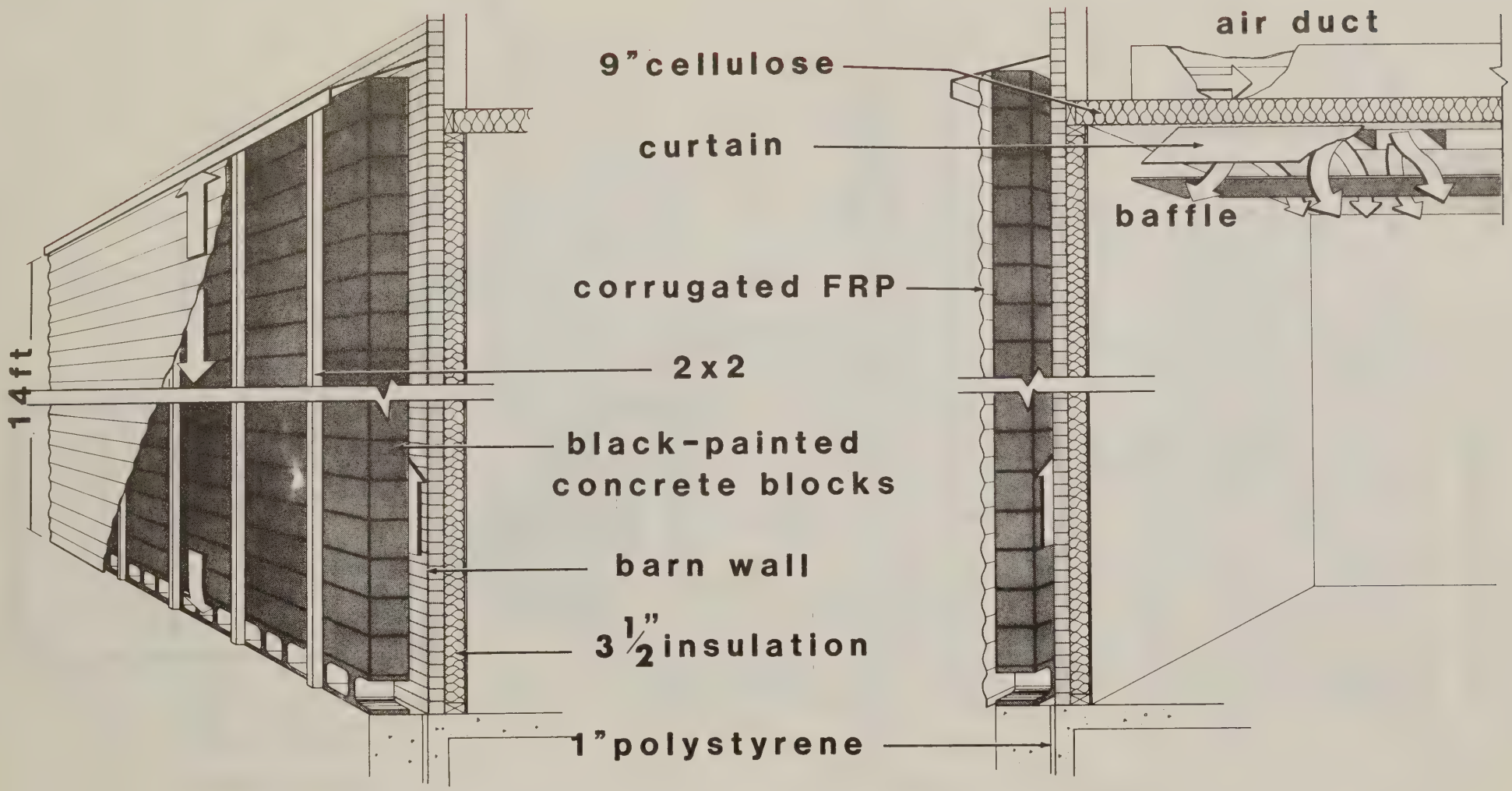


HOFFMAN FARM

COLLECTOR NO. 5

THE FARM	Jim and Clarence Keller Farm, Dallas Center 500 acres, 1600 hogs/yr.
SOLAR BUILDING	Remodeled clay-tile barn, 1980 35 x 55 with two 35 x 21, twelve-sow farrowing rooms and one 35 x 13, 400-pig nursery with double deck cages Waste removed by flush gutters to 8-ft deep outside pit Pigs moved to nursery at 3 weeks, moved out at 40 lbs. Insulation: 3½" fiberglass in walls, 9" cellulose in ceiling, 1" polystyrene around perimeter 60,000 Btu/h LPG heater plus hot water floor heat in each farrowing room, hot water radiant heat in nursery Winter ventilation: 350 cfm in each farrowing room, two 350 cfm continuous fans plus 2380 cfm fan on thermostat in nursery
COLLECTOR DESCRIPTION	Concrete block wall-type collector set on footing along south end of barn 14 x 30, 420 ft^2 Corrugated FRP cover Black-painted concrete block absorber Vertical, wood 2 x 2s form air channels Block cores were filled with concrete to form 8" thick heat storage wall Air enters screened inlet in overhang built over collector, moves down front of wall, under wall, up behind it to insulate duct in hay loft. Air distributed to rooms through ceiling inlets under duct in loft. Airflow: 2.9 cfm/ft^2
COST	\$15.00/ft^2
PERFORMANCE	56% efficiency 1.47 gal LPG/$ft^2 \cdot yr$ projected fuel savings
COMMENTS	Although performance is excellent, high first cost will be hard to recover. Use of more salvaged materials and farm labor would reduce first cost. Need a thermostatically controlled inlet to nursery that opens when large fan comes on. This would avoid wasting solar heat when farrowing rooms need heat but nursery doesn't.

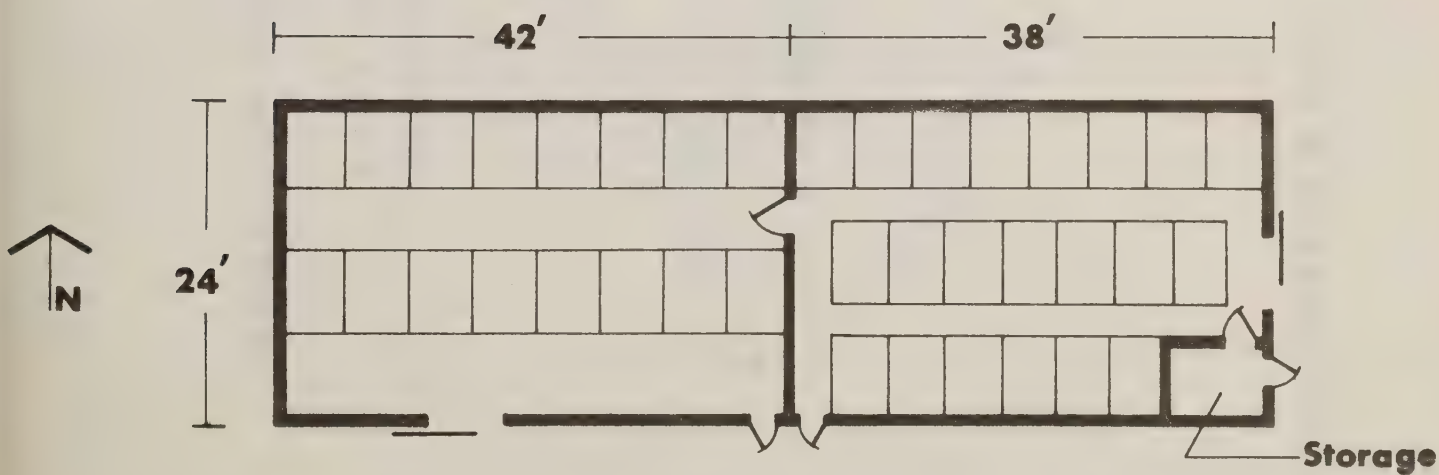



air duct
9"cellulose
curtain
baffle
corrugated FRP
14 ft
2x2
black-painted
concrete blocks
barn wall
3 1/2" insulation
1"polystyrene

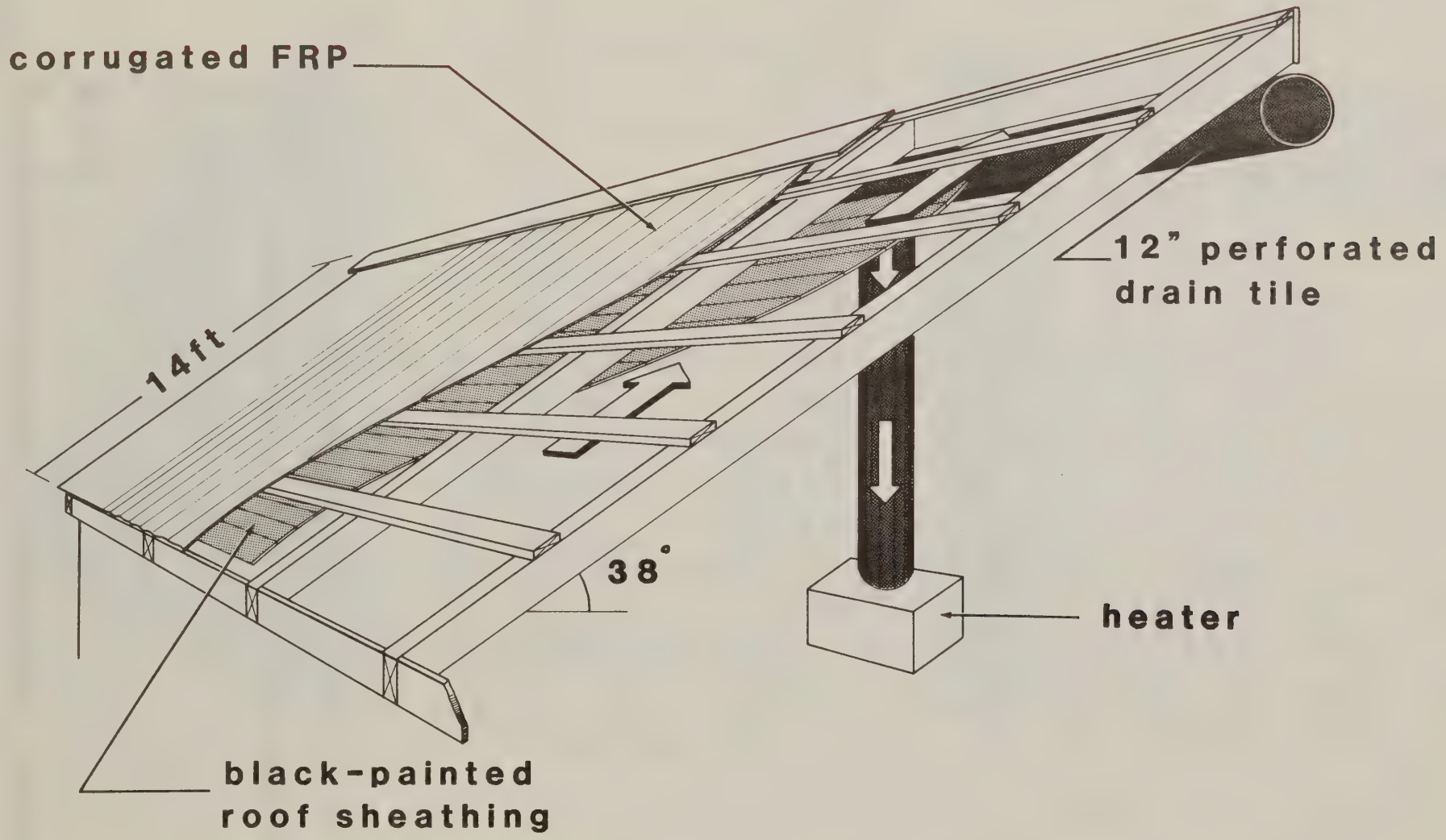
KELLER FARM

COLLECTOR NO. 6

THE FARM	Kerns Ag. Co. Farm, Rolfe 1130 acres, 2500 to 3000 hogs/yr.
SOLAR BUILDING	24 x 80 older farrowing house, collector added 1980 Two farrowing rooms for a total of 38 sows 4' deep manure pit Pigs weaned and moved out at 4-5 weeks Insulation: 3½" fiberglass in walls, ceiling, and north roof 140,000 Btu/h LPG heater in west room; 70,000 Btu/h LPG heater in east room One 12" continuous exhaust fan on pit
COLLECTOR DESCRIPTION	When roof needed reshingling, old sheathing boards were removed, nailed under rafters and painted black and roof was covered with corrugated FRP 988 ft^2 collector area, 38° tilt angle No heat storage Fans in room heaters pull attic air into a 12" perforated tile at the roof peak and then down into the farrowing rooms. Air moves past the absorber primarily by natural convection. Burners in the heaters come on if attic air is not warm enough. Airflow: 0.4 cfm/ft^2
COST	$2.90/$ft^2$
PERFORMANCE	16% efficiency 0.46 gal $LPG/ft^2 \cdot yr$ projected fuel savings
COMMENTS	Performance could be improved by closing in air channels on absorber so that air moves by forced rather than natural convection. Collector adds to summer cooling load.



Farrowing house with solar collector in roof

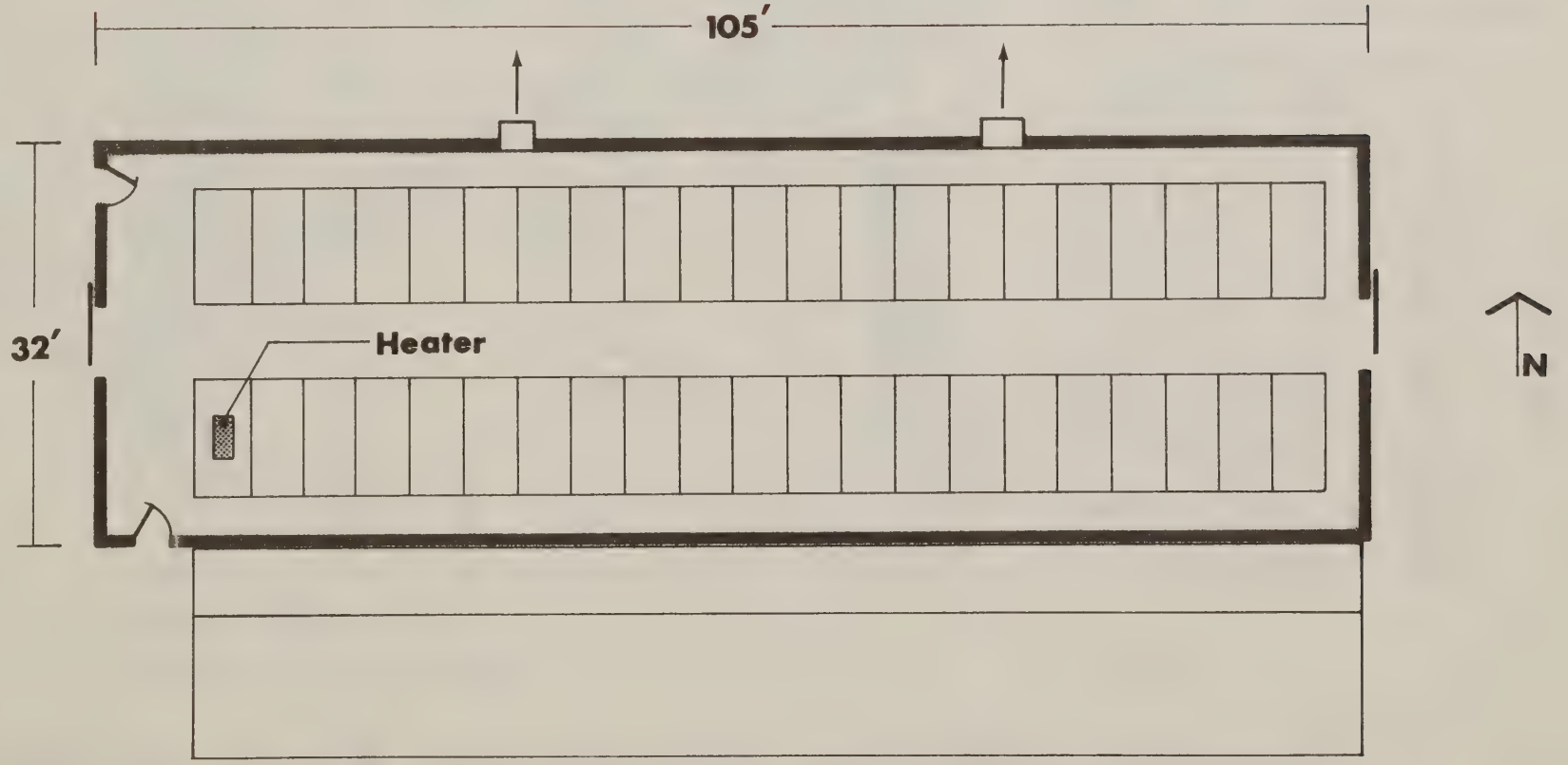


NOTE: air enters attic through opening in endwalls

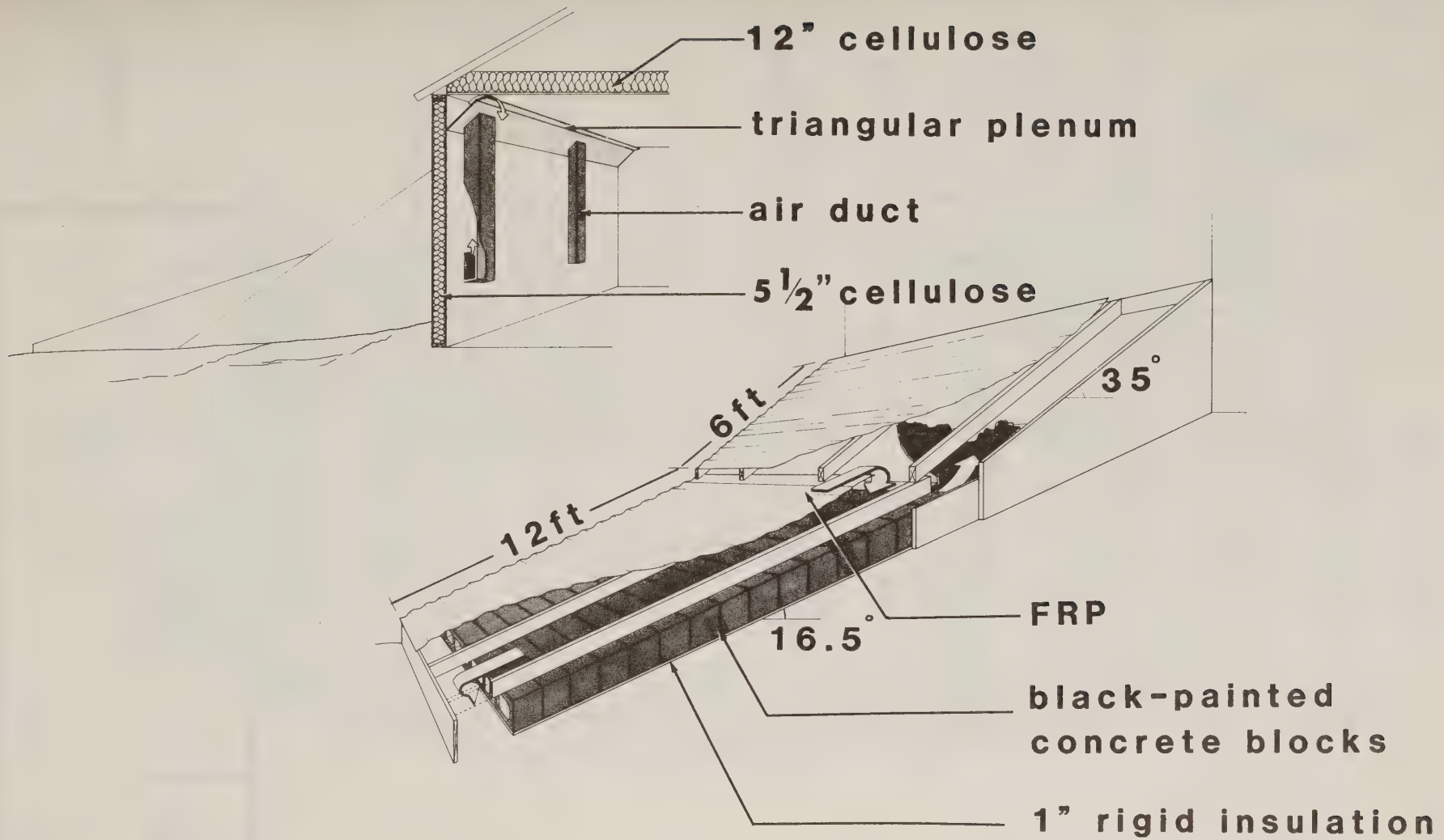
KERNS FARM

COLLECTOR NO. 7

THE FARM	Larry Knaack Farm, Correctionville 460 acres, 2000 hogs/yr.
SOLAR BUILDING	32 x 105, 42-pen farrowing house, built in 1979 Manure is pushed into center alley and then out of building Pigs are weaned at about 4 weeks and moved out Insulation: 5½" cellulose in walls, 12" in ceiling, 1½" polystyrene around perimeter 50,000 Btu/h LPG heater plus heat lamps over pig creeps Two 600 cfm fans are controlled by timers to produce about 30 cfm per sow and litter
COLLECTOR DESCRIPTION	Two sections built on south slope next to building Corrugated FRP cover Black-painted concrete blocks for absorber and heat storage Lower section: 12 x 96, 1152 ft^2; 16.5° tilt angle; concrete blocks lined up on sheets of rigid insulation on ground; 2 x 4s form air channels above blocks Upper section: 6 x 96, 576 ft^2; 35° tilt angle; triangular shaped plenum filled with loose stack of concrete blocks Air enters opening where cover changes slope, moves down block surface between 2 x 4s, moves up through block cores into plenum, into 4 ducts on south wall, and out through baffle held by light springs.
COST	\$2.78/ft^2
PERFORMANCE	23% efficiency 0.61 gal LPG/$ft^2 \cdot yr$ projected fuel savings
COMMENTS	Snow accumulation on the collector is a problem. Changing cover corrugations to run parallel to slope would help somewhat. Collector inlet needs a screen to prevent entrance of corn husks and trash.



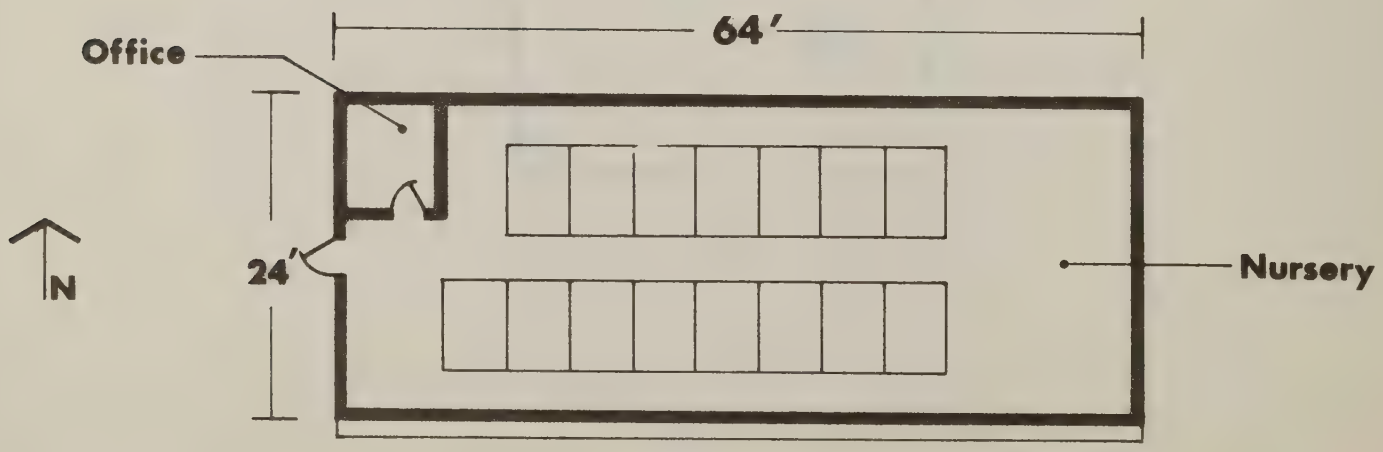
Knaack solar farrowing house. Collector is on south slope next to building.


12" cellulose
triangular plenum
air duct
5½" cellulose
35°
6ft
12ft
FRP
16.5°
black-painted
concrete blocks
1" rigid insulation

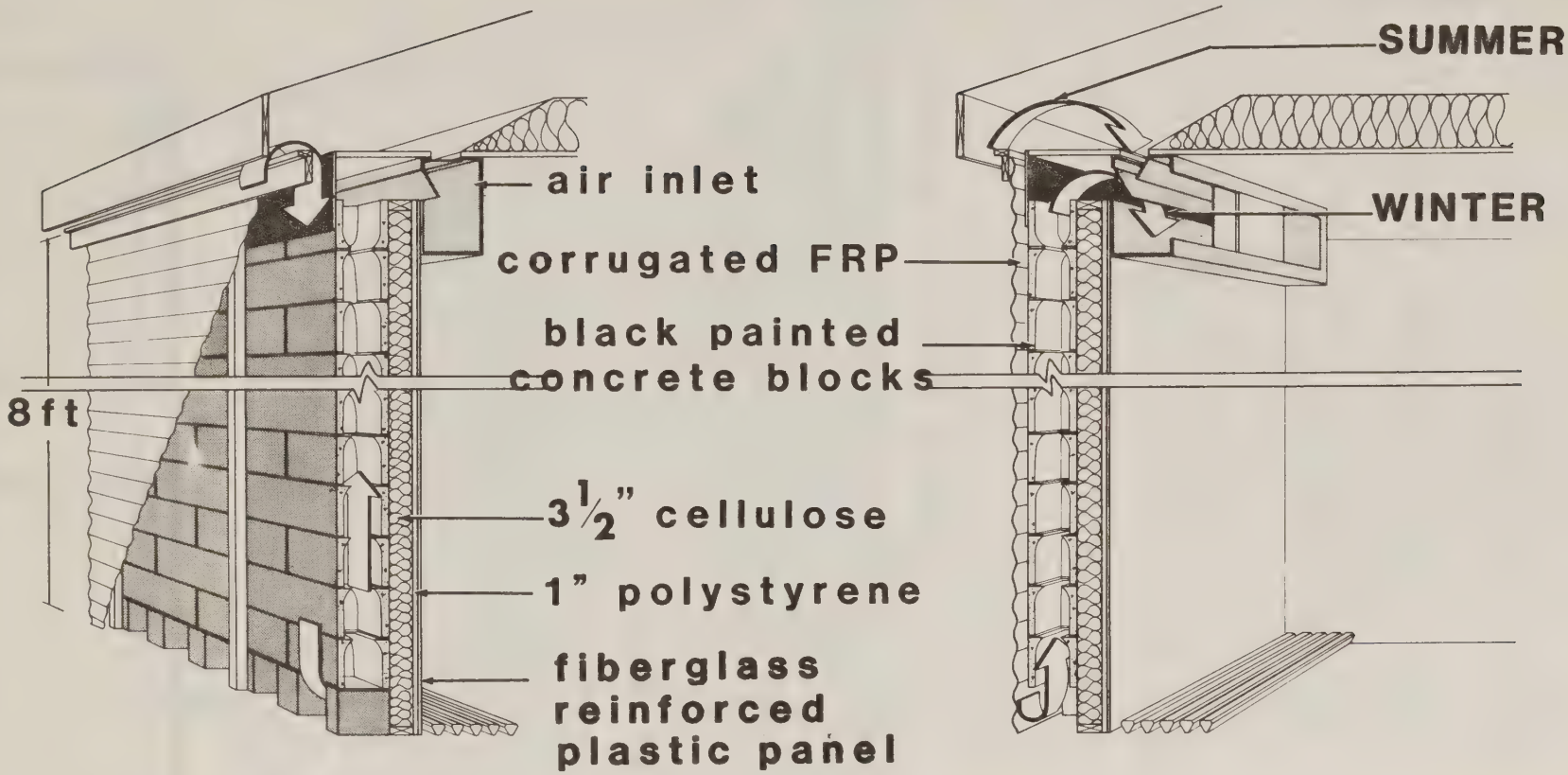
KNAACK FARM

COLLECTOR NO. 8

THE FARM	Jerald McCaw Farm, Williamsburg 1300 acres, 800-1000 hogs/yr.
SOLAR BUILDING	24 x 64 farrowing house and nursery, built in 1979 15 farrowing crates plus nursery space at east end Pigs moved to nursery area at 3-4 weeks and moved out at 40 lbs. Manure stored in 7' deep pit under floor Insulation: 3½" cellulose plus 1" polystyrene in south wall, 6" fiberglass plus 3/4" polystyrene in other walls LPG heater provides backup heat Winter ventilation provided by adjustable speed fan
COLLECTOR DESCRIPTION	Concrete block wall collector integrated into south building wall 7½ x 64, 480 ft^2 Corrugated FRP cover Black-painted concrete blocks for absorber and heat storage Vertical wood 2 x 2s form air channels Air enters screened inlet at eave, moves down wall face, up through block cores, into rectangular wooden duct having 6 openings with sliding doors Airflow: 2.0 cfm/ft^2
COST	\$5.26/ft^2
PERFORMANCE	40% efficiency 1.05 gal LPG/ft^2·yr projected fuel savings Building uses about half as much LPG as a nursery half as large as the solar building
COMMENTS	Very large energy savings produced simply by measuring fan airflow and reducing to proper level. Collector provides good performance at reasonable cost.



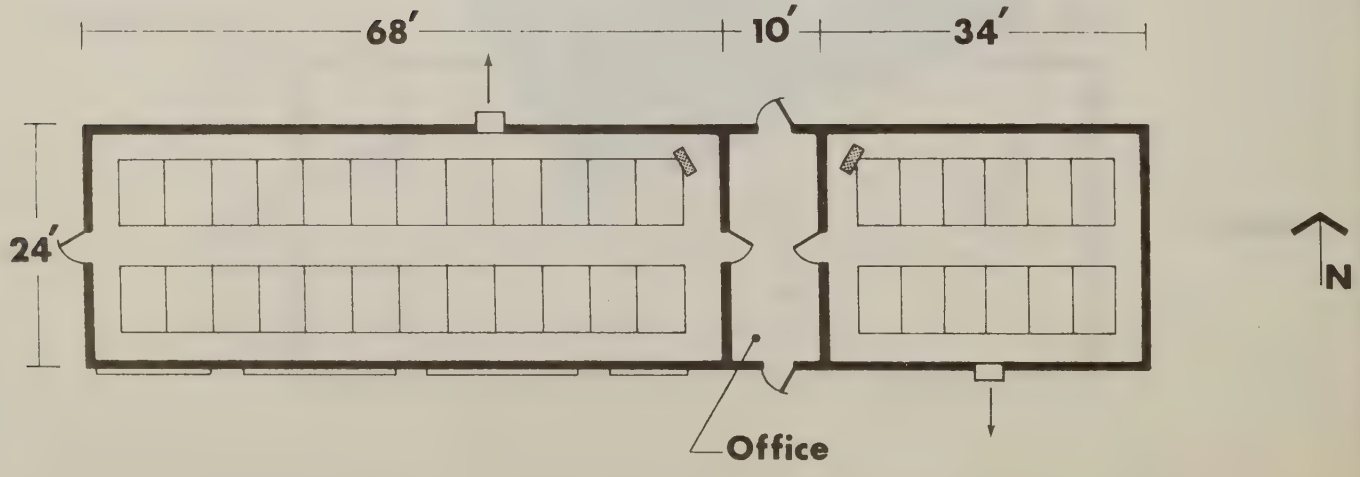
*summer inlet is closed in winter; winter inlet is closed in summer.

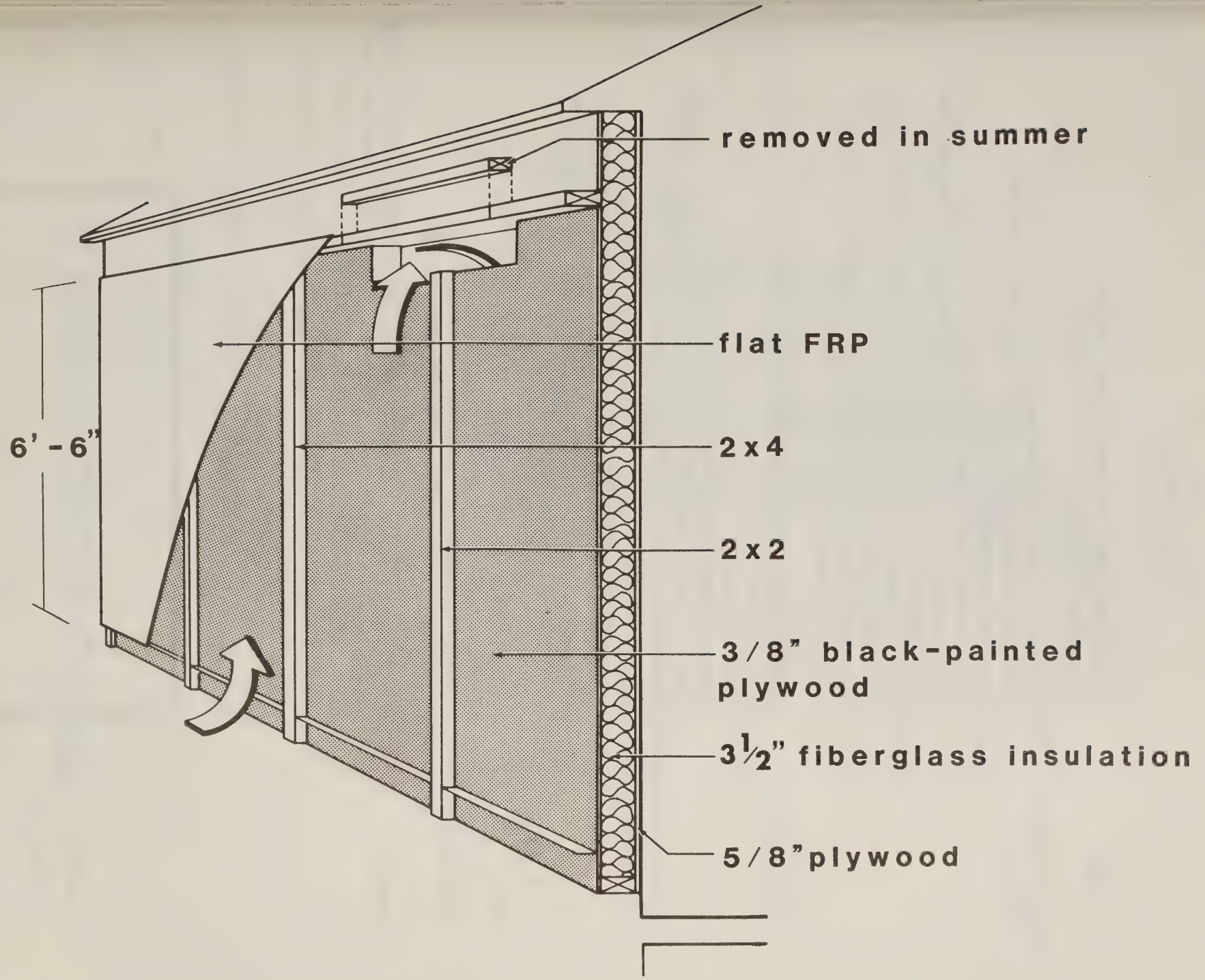


McCAW FARM

COLLECTOR NO. 9

THE FARM	Murley Farms, Inc., Aurora 1600 acres, 2400 hogs/yr.
SOLAR BUILDING	24 x 112 farrowing building, 2 rooms 24-sow west room has solar heat, 12-sow east room does not 4' deep manure storage pit under floor Pigs weaned and moved out at 4 weeks Insulation: 3½" polystyrene in walls, 12" cellulose in ceiling Electric floor heat plus LPG heater in each room Small continuous ventilation fan plus larger fan controlled by thermostat in each room
COLLECTOR DESCRIPTION	Vertical collector added to south wall of west room in 1979 Total size: about 6½ x 52, 330 ft^2 Flat FRP cover Black-painted plywood absorber Air channels formed by vertical 2 x 2s and 2 x 4s (flat) No heat storage Outside air enters screened opening at collector bottom, goes up through hole cut in side wall, past homemade baffle into building In summer, top of collector frame is opened and ventilation air enters room through ceiling inlets Airflow: 1.3 cfm/ft^2
COST	\$4.35/ft^2
PERFORMANCE	33% efficiency 0.88 gal LPG/ft^2·yr projected fuel savings Solar heated room uses about 2/3 as much LPG per sow and litter as non-solar room
COMMENTS	Polystyrene insulation in wall behind collector deteriorated and had to be replaced with fiberglass.

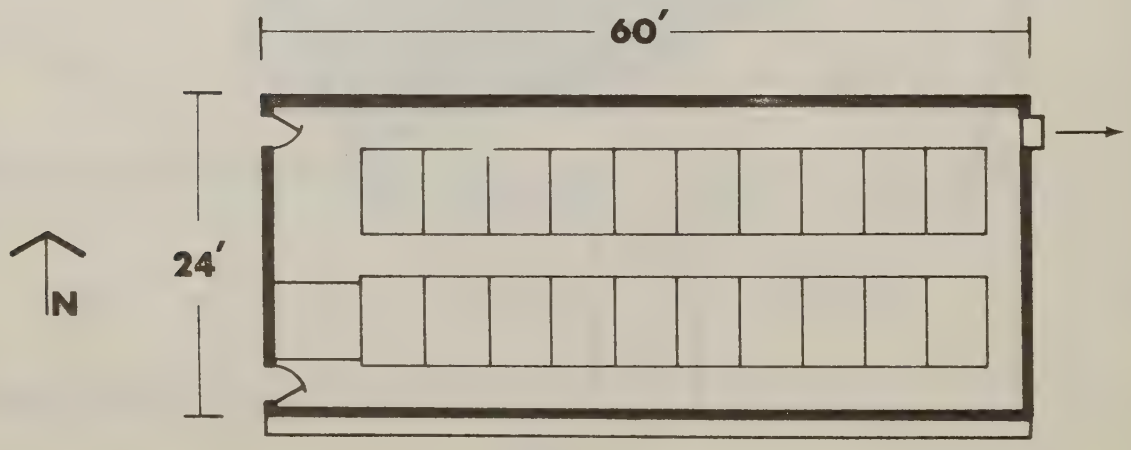


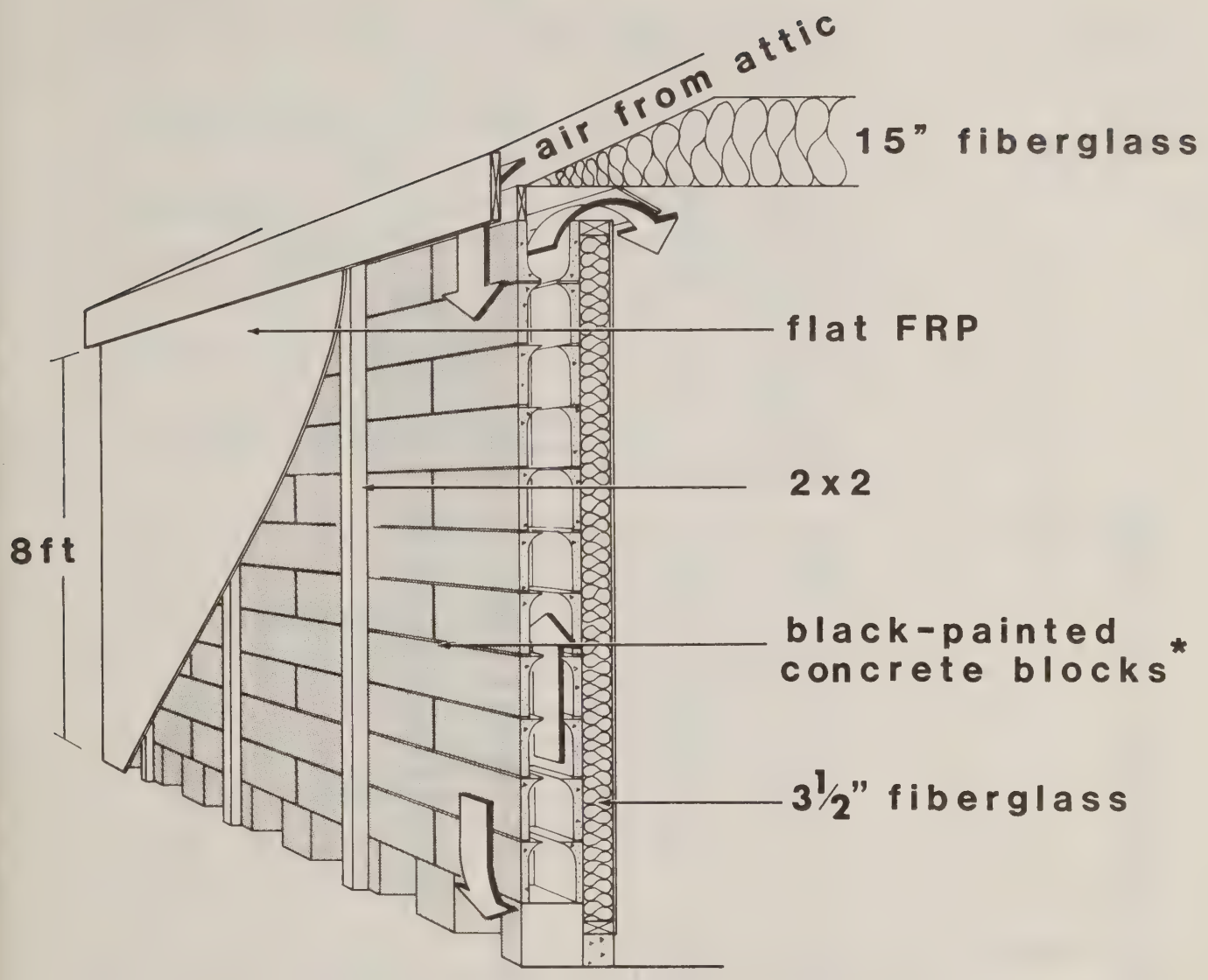

removed in summer
flat FRP
6' - 6"
2 x 4
2 x 2
3/8" black-painted plywood
3½" fiberglass insulation
5/8" plywood

MURLEY FARM

COLLECTOR NO. 10

THE FARM	James and Dave Prestemon Farm, Waukon 350 acres, dairy cattle, 750 hogs/yr.
SOLAR BUILDING	24 x 60 farrowing building, built in 1979 20 raised crates, gravity drain gutters remove waste to outside pit Pigs weaned and moved out at 20-25 lbs Insulation: 6" fiberglass in north, east, and west walls, 15" fiberglass in ceiling 150,000 Btu/h LPG heater plus catalytic heaters and heat bulbs over crates Ventilated by 468 cfm fan which is operated intermittently when building is not full
COLLECTOR DESCRIPTION	South building wall is concrete block-wall-type collector 8 x 60, 480 ft^2 Flat FRP cover Black-painted concrete block absorber Every other core filled with sand (changed to crushed limestone later on) to provide additional mass for heat storage Air channels formed by vertical wood 2 x 2s Exhaust fan pulls attic air down past wall face, up through block cores, through hinged baffle into room Airflow: 1.0 cfm/ft^2
COST	\$5.71/ft^2
PERFORMANCE	24% efficiency 0.62 gal LPG/$ft^2 \cdot yr$ projected fuel savings
COMMENTS	Efficiency would probably improve if building and collector were sealed better and airflow restrictions removed from collector. Some sand leaked out of block cores - now being replaced by crushed limestone.





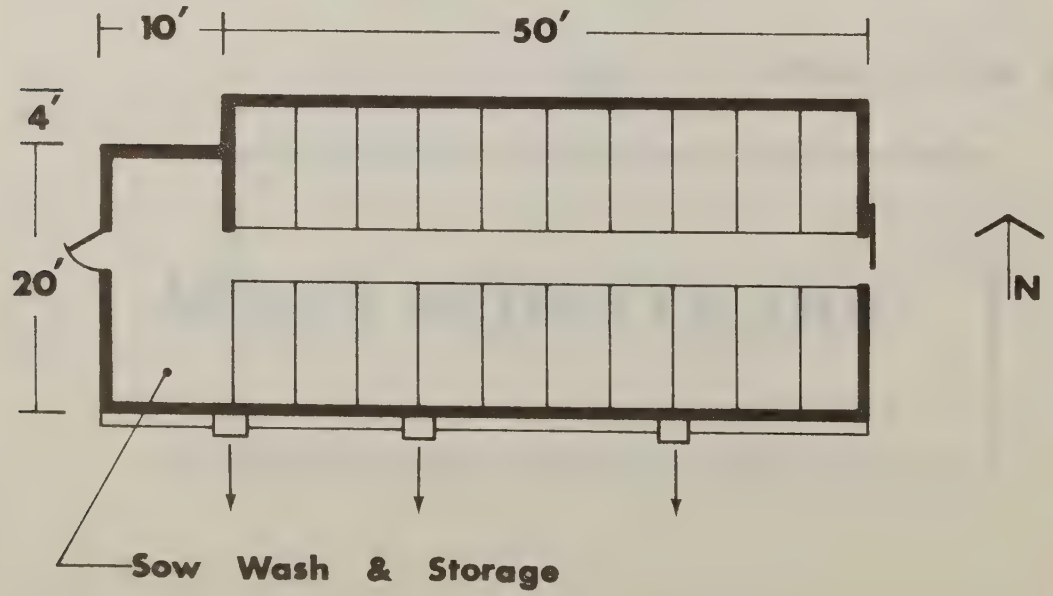
*every other core

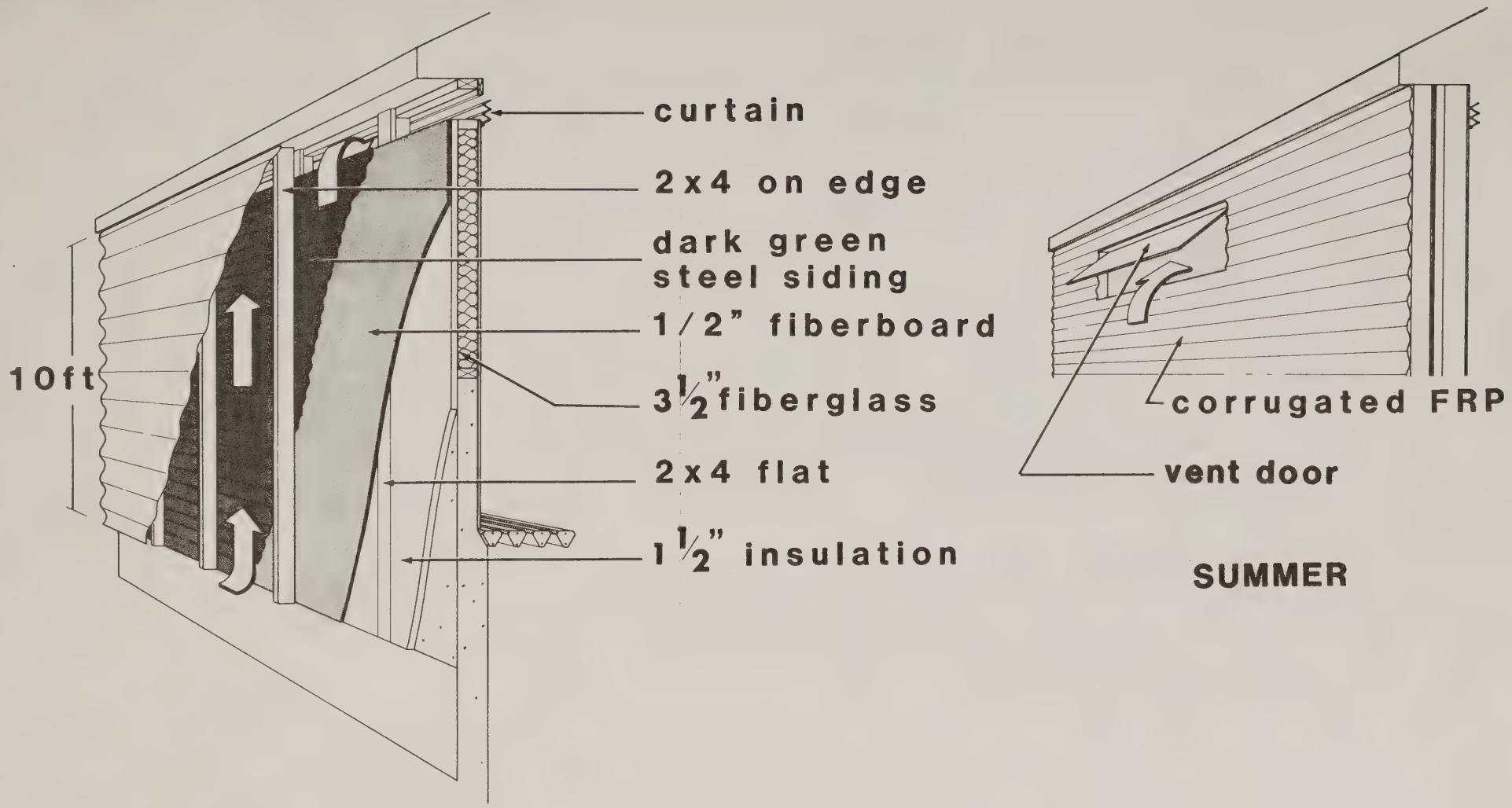
filled with sand

PRESTEMON FARM

COLLECTION NO. 11

THE FARM	Larry Wilson Farm, Moneta 300 acres, 3000 hogs/yr.
SOLAR BUILDING	24 x 50 swine nursery plus 10 x 20 storage and sow wash area, built in 1978 20 pens, 2 sows and litters per pen 7½' deep pit along north and south sides of building Sows and pigs moved in when pigs are 1 week, sows moved out after 3 weeks, pigs moved 2 weeks later Insulation: 3½" fiberglass plus ½" fiberboard in sidewalls, 12" cellulose in ceiling Two 70,000 Btu/h natural gas heaters plus heat lamps in creep area Ventilated by 3 variable speed pit fans Size of air inlet changed by manually adjusting curtain every morning and night
COLLECTOR DESCRIPTION	Added to outside of south wall About 10 x 60, 552 ft^2 Corrugated FRP cover Dark green corrugated metal absorber (chose pre-painted metal, couldn't get black) Air channels formed by vertical 2 x 4s on edge Parts of cover can be removed to allow natural ventilation of nursery in summer Exhaust fans pull air up sidewall, past inlet curtain, and down through floor slats Airflow: 1 to 6 cfm/ft^2
COST	\$1.71/ft^2
PERFORMANCE	36% efficiency 0.95 gal LPG/$ft^2 \cdot yr$ projected equivalent fuel savings
COMMENTS	Collector performance is moderate, but low first cost leads to very good merit figure.

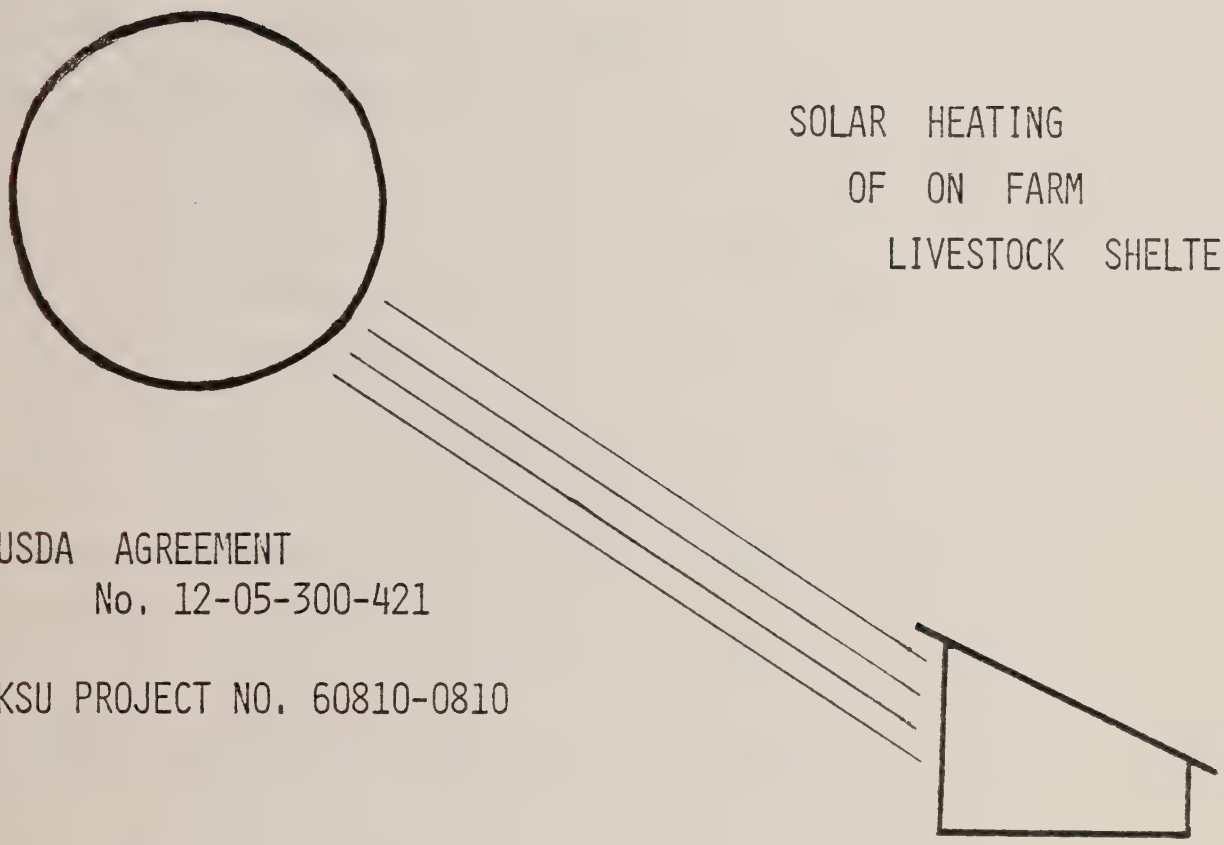



curtain
2x4 on edge
dark green
steel siding
1/2" fiberboard
3 1/2" fiberglass
2x4 flat
1 1/2" insulation
10ft
corrugated FRP
vent door
SUMMER

WILSON FARM

KANSAS

FINAL REPORT



SOLAR HEATING OF ON FARM LIVESTOCK SHELTERS

USDA AGREEMENT
No. 12-05-300-421

KSU PROJECT NO. 60810-0810

by

James P. Murphy
Michael D. Schwarz
Francis V. Robbins

EXTENSION AGRICULTURAL ENGINEERING
KANSAS STATE UNIVERSITY
MANHATTAN, KANSAS 66506

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Introduction

This final report concerns the Kansas portion of the USDA Agreement No. 12-05-300-421 entitled "Solar Heating of on Farm Livestock Shelters." The purpose of the project was to demonstrate actual on-farm uses of solar energy for livestock shelters.

The objectives of this project were:

1. To expand an already existing effort to demonstrate the technical and economic feasibility of using solar energy to produce heat for the on-farm livestock shelters.

2. To on-farm test the technology developed under the DOE/USDA SEA Federal Research Program.

3. To demonstrate on-farm methods of conserving energy without radically changing the normal operation of the livestock facility.

4. To identify areas of feasible and non-feasible solar heat usage that need further research.

5. To utilize a low-maintenance collector and equipment which can be locally purchased and maintained.

6. To measure the energy saved by using the collector so that an economic analysis and payback period can be established.

7. To give as much public exposure to the demonstrations as the owner will permit and publicity methods will allow.

The nine solar demonstrations on swine buildings utilized for this demonstration were:

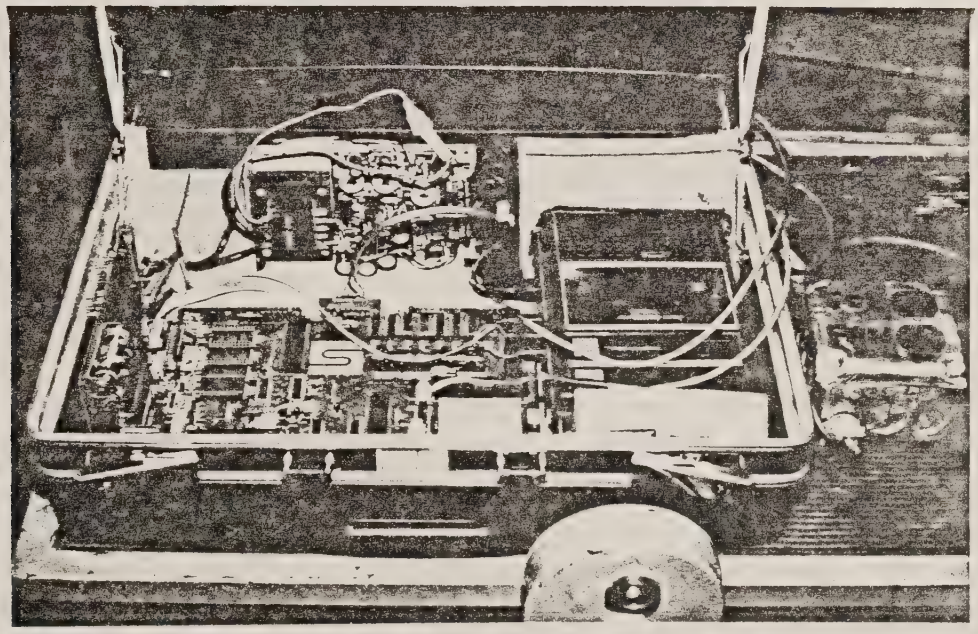
1. Goertzen Farm
2. Hobson Farm
3. Hund Farm
4. Keesecker Farm
5. Pifer Farm
6. Premium Pork Farm
7. Valley View Farm
8. Visser Farms
9. Wedel Farm

The collectors were 50% cost shared up to a maximum of $2,500 by the project. Collectors were installed during 1979 and 1980. Data were gathered on the collectors during the heating season of 1980 and 1981 to determine their energy saving capability.

Performance Data Collection and Engineering Analysis

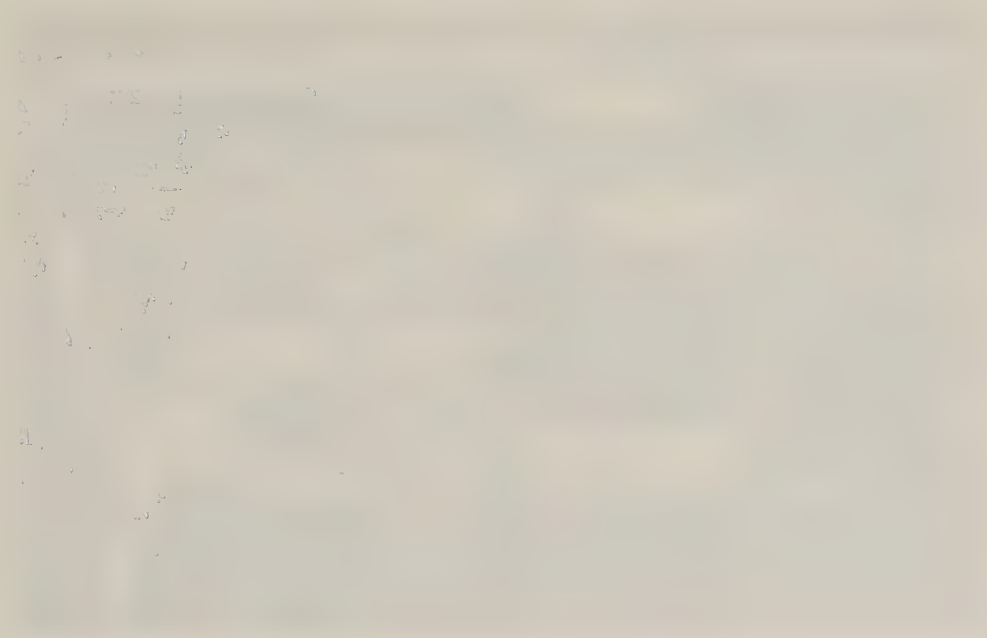
At each installation, sufficient hourly data were collected to determine the amount of solar energy supplied to the building by the solar collection system. These data included temperature increase and flow rate of the solar heat transfer fluid, usually ventilating air. Ambient air temperature and room air temperature were also measured at each location.

The data were collected and recorded on audio cassette tapes by a microcomputer-based, Synertek model SYM-1, data logger. All sensors were sampled once per minute and the values were averaged for the hourly recorded value. Temperatures were sensed with a temperature sensitive integrated circuit, (Analog Devices model AD590) which produces one microamp current change per degree Kelvin temperature change. Air flow rates were monitored with a small mass flow meter designed and built during this project. The meter works on the principle of a hot-wire anemonmeter and produces a voltage (from thermocouples) inversely proportional to mass flow rate. These meters were calibrated in place using a hot-wire anemometer. The meters are quite simple and inexpensive, and we have found them to be both reliable and reasonably accurate.



SYM-1 based Data Logger for Data Collection

A simple accounting of the energy supplied to a building by a solar collector is not adequate to establish the actual fuel saved by the solar collector. The energy flows of a building and its demand for supplemental heat must also be established to determine what portion of the total solar energy



supplied actually saves fossil fuel. We performed an hourly energy balance on each building to estimate fuel savings. Sensible heat production of the animals in the building was included. Measured room temperature let us establish the furnace setpoint temperature. Whenever the room temperature was above the setpoint and the space heaters were off, the sensible heat production of the animals in the building was determined and was accumulated into a running average.

The results of the hourly energy balances were accumulated for daily, weekly, and overall performance. A summary of the measured heating results is included in this report for each site. The parameters in the summaries vary somewhat from site-to-site, but they generally include: average outside temperature, average temperature of solar heated air, average building temperature, average air flow rate through system, total collected solar energy, total building supplemental heat demand, total fossil fuel energy saved, fossil fuel saved, and solar fraction of the total heat demand. Values are included for each data period and for the overall period of data collection.

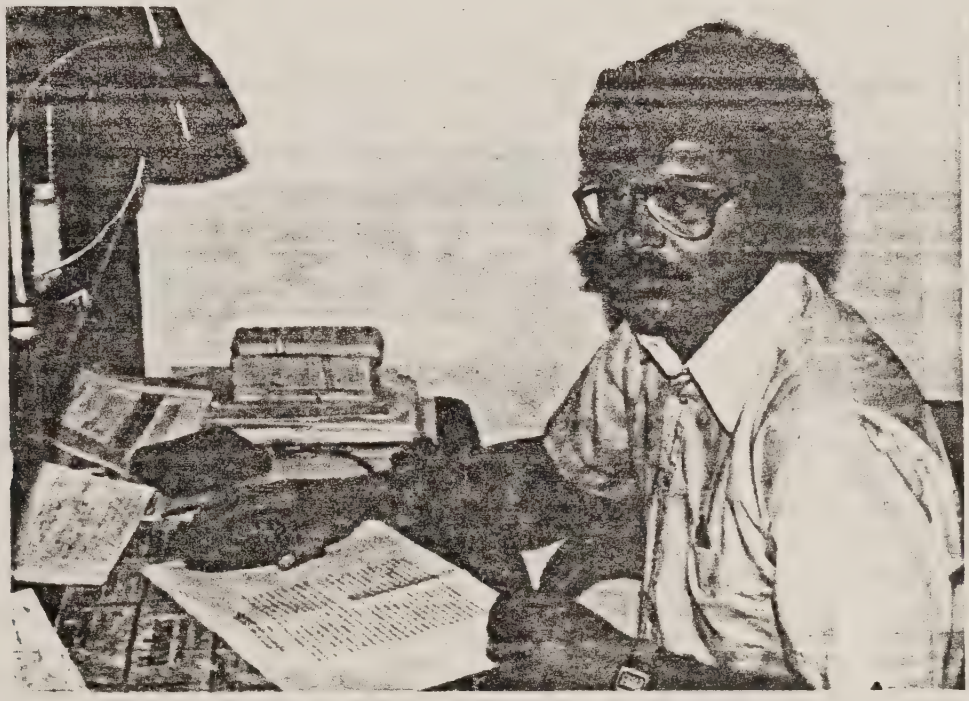
Projecting Typical Annual Performance

Based upon information learned from the monitored performance of each solar-assisted livestock shelter, we projected the typical annual performance of each unit. For the seven buildings that utilize the KSU Solar Wall, the projection procedures were very similar. This solar collector-storage system was developed at Kansas State University through a USDA-DOE research grant. The performance of this system was studied quite extensively and a mathematical model of its operation was developed and validated (Robbins and Spillman 1980). The mathematical model was solved by numerical methods and programmed for computer simulation of performance. Many simulations of the annual performance of this solar collection system on swine farrowing buildings were performed using the "typical meteorological year" (TMY) data from the NOAA. The results of these simulations were put in terms of two dimensionless parameters: monthly collected solar energy divided by monthly building heat demand, and monthly fuel saved by solar energy divided by monthly collected solar energy. These two dimensionless ratios were then correlated to derive a relationship between collected solar energy, building demand for supplemental heat, and actual monthly fuel saved by solar energy.

We used the measured performance results from each installation to determine the typical operation of the building (temperature and ventilating rate) and to develop an equation to predict supplemental heat demand as a function of average daily outside temperature. Then, using long-term (1940-1970 data base) mean monthly temperatures for each site, we predicted typical monthly supplemental heat demand. Monthly collected solar energy was determined by a computer simulation using TMY data from either Omaha, NE or Dodge City, KS, whichever was closest to the site being considered. It was assumed that the collectors operated continuously during the heating season. Then, we used the correlation just described to determine monthly fuel saved by the solar collector.

The projected typical monthly performance is given in tabular form for each of the seven sites with KSU Solar Walls. The annual savings is used in the economic analysis.

Two of the demonstration sites used collectors other than the KSU Solar Wall. For these two installations, the method of projecting typical annual performance is described seperately in the individual sections.



Vic Robbins analyzing data

Life Cycle Economic Analysis of Solar Installations

A life cycle economic analysis, utilizing the discounted present value method, was performed for each installation to determine economic return and feasibility. The analysis was based on the total installed cost of each collector, provided by each cooperator, estimated operation and maintenance costs, and the projected typical annual fuel savings from each collector. The typical annual fuel savings was derived from the measured performance of each installation, and it is discussed for each one in separate sections of this report.

The analysis included the effects of income taxes and solar energy tax credits. In all cases, a ten-year life was used with an appropriate salvage value. Most producers have indicated to us that an investment in solar energy must return its cost with interest within ten years. Assumptions for economic variables for each installation are included in the individual sections along with the economic performance results.

Construction of the KSU Solar Collector

1. The KSU solar collector was used for seven demonstration projects in Kansas. It is basically a preheater type that tempers all incoming air in winter. Shutters in the center of the collector are used to bypass the collector and admit air directly into the building when the solar heat is no longer needed to maintain the building at the proper temperature. The building is designed to be oriented east and west to obtain a south wall exposure.

2. Construction of the collector begins with a concrete foundation two feet wide and extending downward to below frost depth. Reinforcing steel should extend horizontally from the foundation to attach a reflecting sidewalk. The overhang on the south side of the building should extend at least 30 inches from the interior wall. The collector is 24 inches wide, which leaves a minimum of a six-inch overhang for icicle problems and summer shading. A hole in the south interior wall is utilized for duct work, which will admit air from the collector to the building.

3. Clay tile, extending from the foundation, is utilized in pumping animal waste from the building if a pit manure storage system is used. Solid concrete blocks are then stacked on top of the foundation. Blocks are normally 16 inches high. All blocks are placed with the 16 inch dimension perpendicular to the foundation. The blocks are stacked leaving a 6-inch air space between the building wall and the back of the blocks. The foundation should be insulated with 1 inch of styrofoam and covered with cement asbestos board.

4. The blocks are stacked with four dabs of construction adhesive between the horizontal joints to hold them in place. A 3/16-inch wide vertical crack is left between each block. This 3/16-inch wide slot is used for incoming air so that heat may be exchanged between the block and the air flow through the 3/16-inch wide slot.

5. The blocks are then painted with a petroleum-based flat black paint. Normally, two coats are required to get a good surface for absorbing incoming radiation.

6. At this stage of construction, the top of the block wall is sealed and insulated to reduce heat loss through the roof. Normal height of the block wall is about eight feet.

7. White pine wood strips (3/4 inch by 1 1/2 inch wide) are then nailed and glued to the black face. These vertical wood strips are painted white and spaced 2 to 2 1/2 feet apart. White-painted, (1 3/4 inch x 1 1/2 inch) wood strips are mounted horizontally along the top and bottom of the vertical strips to complete the mounting frame for the first transparent cover. The transparent cover is attached with flathead wood screws. If fiberglass is used, holes should be drilled oversized to allow for thermal expansion and contraction. A two-inch slot at the bottom of the cover is used to admit air to the blocks.

8. An additional 1 1/2-inch wood frame is applied directly over the inner wood frame and transparent cover so that a second transparent cover can be applied. This outer cover has an opening at the top which is screened. Wooden battens are fastened over the outer cover to secure it. Wood screws should be used.

9. Air enters the collector through the screen inlet at the top of the outer cover. This inlet is sized to distribute air along the length of the collector with about a 0.05" H_2O pressure drop. The air then travels downward between the two covers to the bottom of the inner sheet, where it then turns a 180 degree direction to flow through the vertical cracks in the concrete block wall. The air travels through the block wall and into the building through a slot inlet to admit the air to the animal confinement structure. The vertical flow of air between the two transparent sheets reduces the heat loss from the concrete blocks. Snow cover or reflector panels on the ground significantly increase the incoming solar radiation.

10. As summer progresses, the shadow from the six-inch overhang begins to shade the vertical collector. In mid-summer, most of the collector is shaded so that rejection of heat in summertime can be easily accomplished.

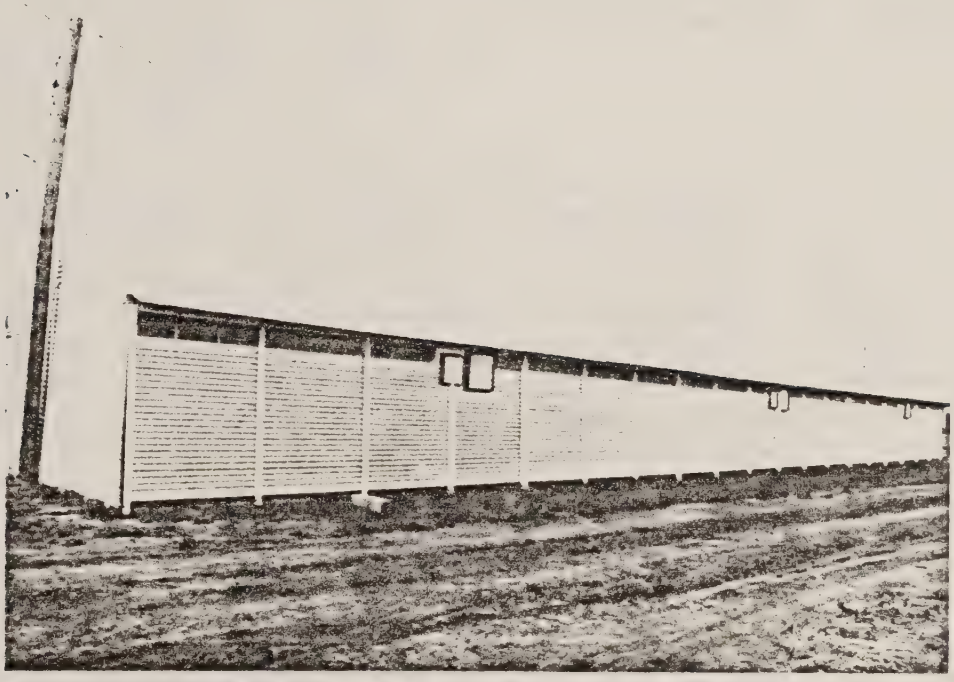
11. Chimneys on the north side of the building enclose exhaust fans which power the ventilation system year round. Air is exhausted vertically from the building to eliminate the strong wind influence in Kansas. During normal winter operation, the fans are the only moving part of the collector, which decreases electrical operation costs of the system.

12. Care must be taken during construction to insure that all joints are as air-tight as possible to guarantee that ventilating air comes through the concrete wall.

13. Construction details are given in plan #81902 available from Extension Agricultural Engineering, Room 237 Seaton Hall, Manhattan, Kansas 66506.

Goertzen Farm Demostration

Goertzen Farm
RR 2
Newton, KS 67114

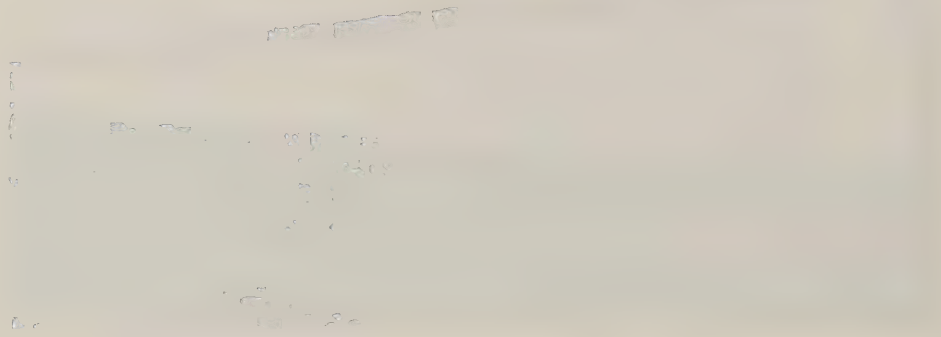


Building:

The building is 26 ft. wide (including solar collector) by 127 ft. long and contains two 38 ft. long farrowing rooms with 14 crates each, a 42 ft. long nursery with 12 pens, and a 9 ft. long office and sow wash room. The building is wood frame construction using 2 x 6 stud walls on the east, north, and west, and a 2 x 4 stud wall on the south side behind the solar collector. The 2 x 6 walls have approximately 3 1/2 inches of sprayed-on polyurethane, and the 2 x 4 wall was filled with blow-in cellulose. Ten inches of cellulose was installed above the ceiling. The exterior shell of the building is enameled sheet metal and the interior lining is painted 1/2 inch exterior grade plywood. The floor of the building (except office) is totally slotted stainless steel with a manure storage pit below. Supplemental heat is provided by a 60,000 Btu/hr non-vented LPG furnace in each room.

Solar Collector:

The solar collector size is 7 1/2 ft. high x 115 ft. long. It is a solar wall, developed at Kansas State University. It consists 2 fiberglass layers supported in front of a massive concrete block wall. Details for construction of the solar collector are given on page 5 of this report.



Fans which are installed in a fan enclosure box on the north side of the building regulate the airflow through the building. These fans cause a vaccum which induces air to flow between the fiberglass covers, and then through the 3/16 inch vertical cracks in the block wall. The blocks then temper the air before it enters the farrowing or nursery rooms. Air withdrawal from the room is accomplished by drawing the air through the slats into the pit area and then proceeding to the fan enclosure where it is exhausted.

This collector has 855 sq. ft. exposed to the sun. The collector cost was $5,800 or $6.78 per sq. ft.

Measured Performance:

Hourly performance data were collected at this building for five weeks during the winter of 1980-1981 and for approximately six weeks during the winter of 1981-1982. These data showed that the building and solar collector operated correctly and nearly continuously. However, when we tried to use these data to evaluate quantitatively the performance of the solar wall on this building, we found there were significant measurement errors in some of the performance parameters we measured. Both outside air temperature and air temperature from the solar wall were erroneous, and we felt we could not use the data with confidence of correct results.

Analysis of the measured performance data was also complicated by the fact that all three of the rooms draw ventilating air from the entire solar wall, but we could monitor only one room. Therefore, we could not determine the airflow rate for the total collector or its total energy output.

We used the measured performance data only to determine that the solar collector operated. No measured performance results were calculated.

Projected Typical Annual Performance:

Measured performance results were not available for this building as discussed in the previous section. Therefore, we had to base the simulation of this building's performance on our knowledge of the building's design, construction, and mechanical equipment.

To simulate operation of the farrowing rooms, we used a continuous minimum ventilation rate of 51 m^3/h-stall (30 cfm/stall). This rate was specified in the design of the building, and it is typical of farrowing houses in Kansas. The furnace was set at 27 C (80 F). The minimum ventilation rate for the nursery room, which houses pigs from about 10 to 20 Kg, was set at 5.8 m^3/h-pig (3.4 cfm/pig) and the furnace was set at 27 C (80 F). These operating temperatures are based on our observations during two winters. The ventilation rates for the three rooms result in an airflow rate of approximately 41.6 kg/h per square meter of solar wall (1.97 cfm/ft^2) assuming all the minimum ventilation enters through the solar collector.

Once the operational parameters were determined, the procedure for projecting typical performance of the KSU Solar Wall on this building was as described on page 3. Long-term monthly mean temperatures for central Kansas were used in the building simulation, and 'typical meteorological year' data

for Dodge City, Kansas were used for simulation of solar collector performance. The projected typical monthly and annual performance of this building (all three rooms combined) is presented in Table G1.

Table G1. Typical Monthly Performance of the Goertzen Solar-Assisted Swine Building

Month	Collected[1] Solar mJ/m^2	Collection Efficiency %	Heat[2] Demand mJ/m^2	Energy Saved mJ/m^2	Fuel Saved l/m^2	Solar Fraction %
Jan.	274	59	596	265	12.6	44
Feb.	250	55	435	220	10.5	51
Mar.	236	52	330	185	8.8	56
Apr.	165	47	122	91	4.3	75
May	124	41	47	35	1.7	75
Sept.	229	55	25	23	1.1	92
Oct.	302	60	104	75	3.6	72
Nov.	249	59	301	177	8.4	59
Dec.	229	58	492	224	10.7	46
Annual	2058	55	2452	1295	61.7	53

1. Collected solar energy is from simulated performance using Dodge City, Kansas data and 41.6 kg/m^2 -h collector airflow rate.
2. Supplemental heat demand calculated using long-term mean temperatures for central Kansas. All energy quantities stated per square meter of solar collector.

In a typical year, we predict the 80 square meter KSU Solar Wall on this building saves 1295 mJ per square meter (114,000 Btu/ft^2). This is equivalent to 4940 liters of LPG (1306 gal) per year.

Economic Feasibility Analysis:

The Goertzen swine building is heated by the KSU solar Wall and non-vented space heaters fueled by LPG. Assuming the space heaters are 90% efficient, the projected typical annual fuel saved by the collector is 61.7 liters per square meter (1.51 gal/ft^2). The total installed cost of this solar collector-storage unit was $72.95 per square meter of collection surface ($6.78/$ft^2$). With this cost and projected annual fuel savings, we performed a life-cycle economic analysis using parameters in the following list. The analysis reveals that this solar collection system will pay for itself in saved fuel in ten years and provide an inflation-adjusted, after-tax annual return of 16% on the invested capital. This return was calculated with the 45% solar tax credits included; however, this collector would provide approximately a 4% inflation-adjusted annual return without the tax incentives and would still be economically acceptable to most swine producers.

Economic Parameters in Analysis

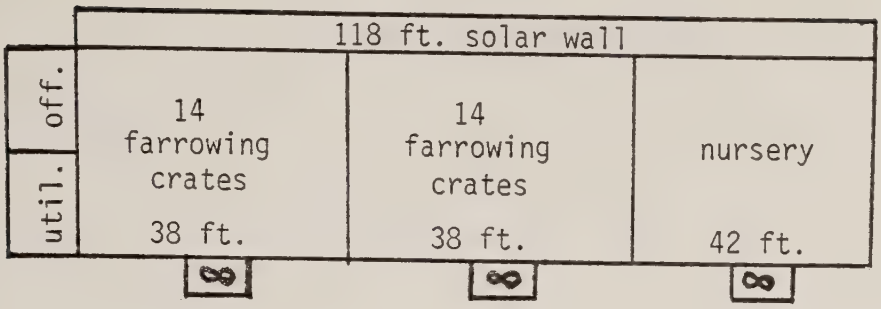
55% tax credit (25% Federal + 30% State)
$20 per square meter salvage value
10 year economic life
$0.15/liters LPG initial fuel cost
10% fuel price inflation
7% general inflation
25% tax bracket

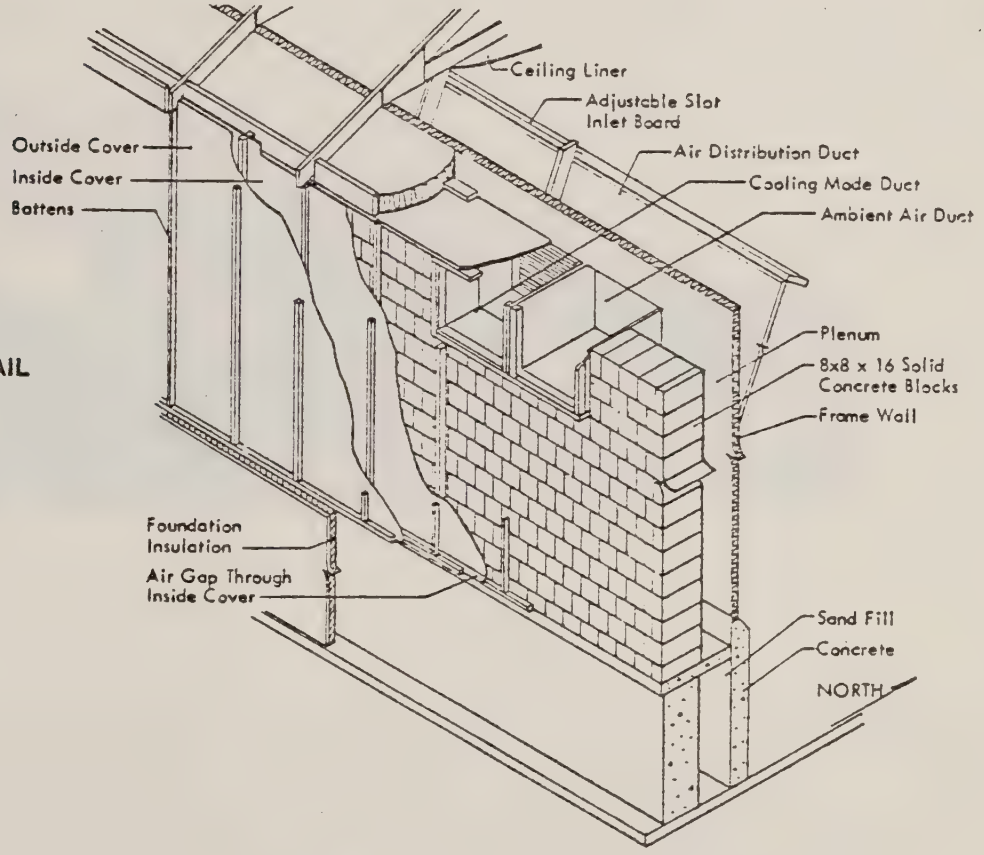
The high rate of return from this solar collection unit means that it could have been sized larger, if physically practical, to provide a greater portion of the building's supplemental heat. We estimate that the collector could have been approximately 50% larger and still provide a 6% inflation-adjusted annual return. It would then supply over 65% of the building's heat demand.



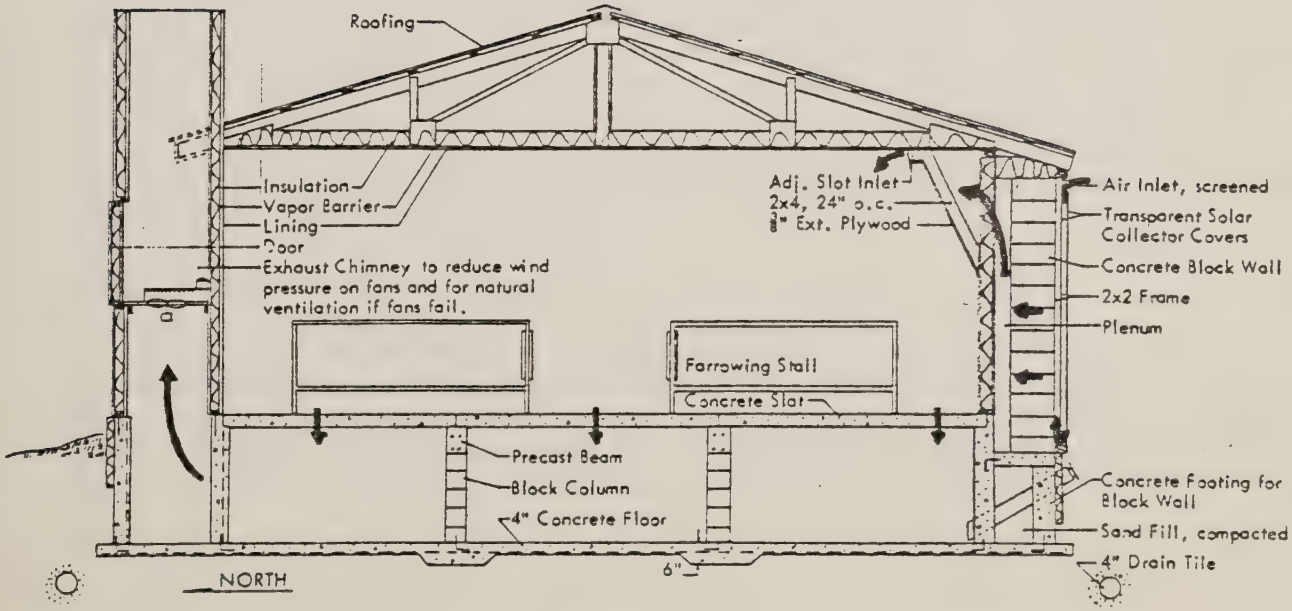
Air Flow sensors were calibrated using a hot wire anemometer

GOERTZEN FARMS, NEWTON, KANSAS





SOLAR WALL DETAIL



CROSS SECTION

Leon Hobson Demonstration

Leon Hobson
Erie, KS 66733



Building:

The building is a 30 ft. x 56 ft. lactation-nursery with open flushing gutters for manure removal. The building utilizes 2 x 6 side walls filled with fiberglass. Eighteen-inch wide ventilation openings run full length of the building on the north and south sides. The openings have adjustable curtains which contain a 1 inch polystyrene insulation board. The curtains are nearly closed during the heating season and all ventilating air is admitted through the solar collector. The roof structure is a rigid frame filled with 9 inches of fiberglass. The pens are sized 6 1/2 ft. wide by 13 ft. long with a 4 ft. wide open gutter toward the outside walls of the building. The building has a capacity of 16 sows with litters plus 200 weaned nursery pigs. The exterior covering is enamaled sheet metal and the interior lining is 1/2 inch exterior grade plywood. Supplemental heat is provided with a non-vented, 60,000 BTU/hr propane furnace.

Solar Collector:

The solar collector is a flat plate type with two transparent covers. It is mounted on the south slope of the gable roof which has a 5 on 12 pitch or a 22.6 degree tilt angle for the collector. The absorber plate is galvanized steel painted flat black, and the transparent covers are fiber-reinforced plastic panels. Overall dimensions of the solar collector are 55.5 ft x 17.4

ft for total exposed area of 965 ft^2 (89.7 m^2).

Two fans move ventilating air through the solar collector. Air enters the collector along the south eave and is pulled upslope to a manifold duct at the ridge of the roof. Air can pass both over the absorber plate and between the the two transparent sheets. An 18 inch propellor fan at the west end of the building pulls air from the manifold duct and can discharge the heated ventilating air either directly to the room or into an under-floor rockbed heat storage. The rockbed measures 56 feet long by 18 feet wide by 2 feet deep, and it contains 100 tons of 2 inch diameter rock.

Two ducts at the west end of the building transmit the air down to both the north and south sides of the rockbed. Air is distributed through the rockbed by use of hollow-core concrete block air tunnels. The air moves through the rockbed horizontally toward the center of the building where it enters a full-length exhaust manifold duct. The air then moves to the east end of the building in this duct where it rises to the 12 inch continuous ventilation fan. This fan then distributes the solar-heated ventilating air to the building via a perforated polyethylene tube running through the center of the building.

The original design was to have automatic controls to activate the 18 inch fan whenever air from the solar collector reached a certain temperature. The outlet damper for the 18 inch fan was designed to be automatically controlled to send solar heated air to storage or directly to the room based upon room air temperature. Also, an additional duct and damper was attached to the 12 inch continuous ventilation fan such that it could draw air directly from the solar collector if stored heat was depleted and heat was needed in the building. This damper was also to be automatically controlled. Due mainly to cost, these automatic controls were never purchased by the producer, and the 18 inch fan and both dampers were operated manually.

The cost of the 965 square foot collector, rockbed heat storage duct work, and fans was $5,975 or $6.20 per square foot of collection area.

Measured Performance:

During the winter of 1980-81, this solar collection system operated approximately as it was designed. Air was drawn through the roof-mounted solar collector then forced through the under-floor rockbed before entering the swine confinement room. The small ventilating fan ran continuously and the large fan (18") was activated manually on most clear days to enhance solar collection. At times, the operator manipulated the shutters which allowed solar-heated air to bypass the rockbed heat storage. During such periods, we could not determine the correct airflow rates for the solar collector, rockbed heat storage, or confinement room. However, we did find two data periods when all ventilating air from the small fan was pulled through the collector and rockbed.

The results for the two periods during the 1980-81 winter are presented in the first portion of Table H01. The solar collector and storage system functioned quite well during these two periods. Approximately 90% of the supplemental heat demand was provided by solar energy. A great deal more solar

energy was collected than could be utilized to save fuel, however, even during these relatively cold periods. Only 53% of the collected solar energy saved fuel, but the excess solar heat maintained the building above the furnace set-point temperature of 21 C much of the time and could have provided additional economic benefit through improved animal efficiency and health.

During the 1981-82 heating season, the owner chose to operate the solar collection system with the heat storage by-passed and with the solar-heated ventilating air entering the confinement room directly. No reason was given for this decision; however, it's effect on the performance of the solar collection system was very detrimental. Measured performance of the building during periods in the 1981-82 heating season are presented in the second half of Table H01.

Table H01. Measured Performance of the Hobson Solar-Assisted Swine Building

Time Period	Amb. Temp. °C	Solar[1] Temp. °C	Bldg. Temp. °C	Flow[2] Rate kg/m²-h	Coll.[3] Energy mJ/m²	Heat Demand mJ/m²	Energy Saved mJ/m²	Fuel[4] Saved liter	Solar Frac. %
With Storage Utilized - 1980/1981									
12/18-12/31	5.8	21.2	22.0	14.0	71.1	39.3	36.7	1.75	93
1/1-2/2	7.6	21.4	22.8	14.0	150.1	91.9	81.8	3.89	89
Totals 45 days	7.1	21.3	22.6	14.0	221.2	131.2	118.5	5.64	90
Storage not Utilized - 1981/1982									
1/22-2/3	2.0	4.8	21.1	34.9	48.8	26.2	7.3	0.35	28
2/13-2/25	6.7	8.8	20.0	34.0	36.8	13.7	1.7	0.08	12
3/7-3/18	10.1	12.1	22.2	34.0	33.6	10.6	2.3	0.11	22
Totals 35 days	6.2	8.5	21.1	34.3	119	50.5	11.3	0.54	22

1. Temperature of air leaving the solar collector-storage unit.
2. Airflow rate through solar collector-storage unit.
3. All energy quantities are stated per square meter of installed collector surface area.
4. Liquid petroleum gas equivalent (backup fuel) calculated at 90% of lower heating value (21 mJ per liter).

One can easily determine the effect of eliminating the heat storage capacity from the solar collection system. Again solar energy collected greatly exceeded the buildings need for heat, but only a small fraction (9%) of the collected solar energy actually saved fossil fuel. This building is well-insulated, properly ventilated, has a high animal density, and is maintained at a relatively low (21 C) temperature. Therefore its demand for supplemental heat is low and the great majority of the demand occurs at night. Without heat storage, all collected solar energy was supplied to the building during the daylight hours when ambient temperatures were highest and little demand for heat occurred. It is quite evident from these results that the rockbed heat solar storage should be utilized with this collector.

Projected Typical Annual Performance:

The performance of the Hobson swine confinement building for a typical year's operation was projected by using the measured performance results and our knowledge of the building's design, construction, and operation. In the building simulation, we used; a furnace setpoint temperature of 21 C, a minimum continuous ventilation rate of 1700 m^3/hr (1000 cfm), average building occupancy of 16 sows with litters plus 200-16kg (35 lb) weaned pigs, and continuous floor heating at the rate of 2800 W. The building's operation was simulated using long-term mean monthly temperatures for southeast Kansas.

We simulated performance of the solar collector by using the generalized flatplate solar collector performance equation, Eq. H01. This equation utilizes the mean monthly solar insolation values for a 4 on 12 slope at Dodge City, Kansas (nearest available station) and long-term mean monthly temperatures for southeast Kansas.

$$q_c/A = \dot{m}\, c_p\, (t_o - t_i) = I_T\, \tau\alpha - U_L/f_r \left(\frac{t_i + t_o}{2} - t_{amb}\right) \qquad \text{Eq. H01}$$

For this collector with two fiberglass covers and airflow over the absorber plate and between the covers, appropriate values for coefficients in this equations are; $\tau = 0.65$, $\alpha = 0.96$, $U_L = 2.84$ W/m^2-h, $f_r = 0.95$. With these parameters in Eq. H01, the collector achelves a collection efficiency of 57% when heating outside ventilating air at a flow rate (m) equal to the combined airflow of the 12 inch and 18 inch fans. The owner did not purchase automatic controls to activate the large fan during solar collection. He indicated that he manually activated the large fan on approximately 75% of the clear days. Therefore, we reduced collection efficiency to 46% (80% of the theoretical value).

The projected typical monthly performance for this building appears in Table H02. We have projected typical performance both with and without the utilization of the rockbed heat storage, since the building was operated both ways. To project actual fuel savings, we assumed that the heat storage system in this building would match solar heat supply to building demand. This assumption seems accurate since the projected performance with storage for December and January matches the measured performance. To project fuel savings without solar heat storage, we estimated the building's heat demand during only the daytime hours and assumed the collector could supply 100% of that demand.

Table H02. Typical Monthly Performance of the Hobson Solar-Assisted Swine Building

Month	Collected[1] Solar mJ/m^2	Collection Efficiency %	Heat[2] Demand mJ/m^2	Energy Saved mJ/m^2	Fuel Saved l/m^2	Solar Fraction %
		With Storage Utilized				
Jan.	225	46	92.8	87.8	4.18	95
Feb.	224	46	45.9	42.6	2.03	93
Mar.	296	46	9.0	9.0	0.43	100
Nov.	226	46	7.0	7.0	0.33	100
Dec.	211	46	54.2	48.5	2.31	90
Annual	1182	46	208.9	194.9	9.28	93
		With Storage Not Utilized				
Jan.	225	46	92.8	27.8	1.32	30
Feb.	224	46	45.9	9.2	0.44	20
Mar.	296	46	9.0	0.9	0.04	10
Nov.	226	46	7.0	0.7	0.03	10
Dec.	211	46	54.2	16.3	0.78	30
Annual	1182	46	208.9	54.9	2.61	26

1. Collected solar energy is from simulated performance using Dodge City, Kansas data and 60.6 kg/m^2 -h collector airflow rate.
2. Supplemental heat demand calculated using long-term mean temperatures for southeast Kansas. All energy quantities stated per square meter of solar collector.

Several things are apparent from the results of Table H02. First, this building has a short heating season and requires relatively little supplemental heat to be maintained at the desired temperature of 21 C. Annual projected fuel usage of this building is only 895 liters (237 gal) of LPG. The solar collector on the building's roof can collect much more energy than can be utilized to save fuel in the building. If the heat storage capacity is not utilized, fuel savings and solar fraction drop dramatically.

Economic Feasibility Analysis:

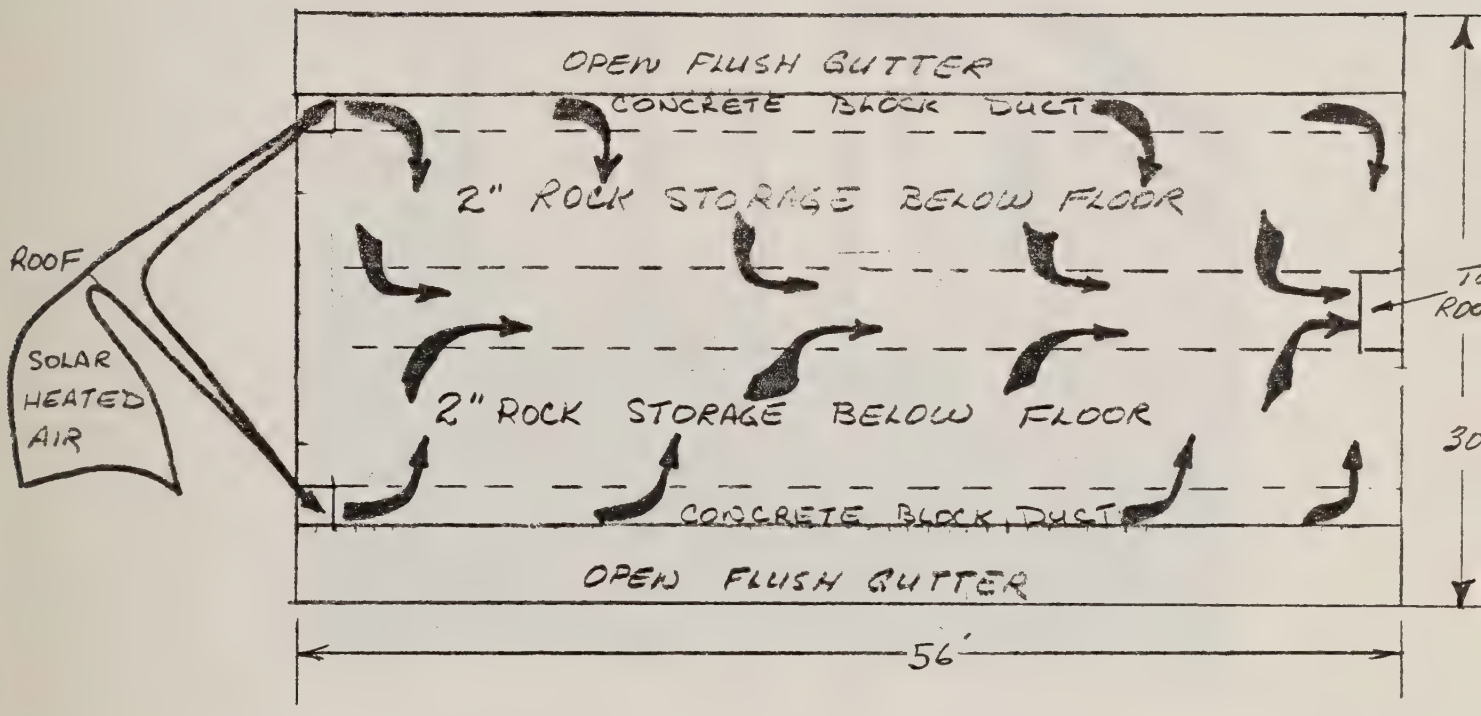
The Hobson solar assisted swine confinement building is provided backup heat by a non-vented space heater fueled by LP gas. Assuming that this heater is 90% efficient and also that the heat storage capacity of the solar collector will be utilized, we project the annual fuel saved by the collector is 9.28 liter of LPG per square meter (0.23 gal/ft^2). The installed cost of the solar collection system on this building was $66 per square meter of collection surface ($6.20/$ft^2$). With this cost and the projected annual fuel savings, a life-cycle economic analysis was performed using economic parameters in the following list. The analysis revealed that this solar collection system will pay for itself in fuel savings over a 10 year period and provide a 1% inflation-adjusted, after-tax annual return on the invested capital. This economic performance would probably be unacceptable to most swine producers.

Economic Parameters in Analysis

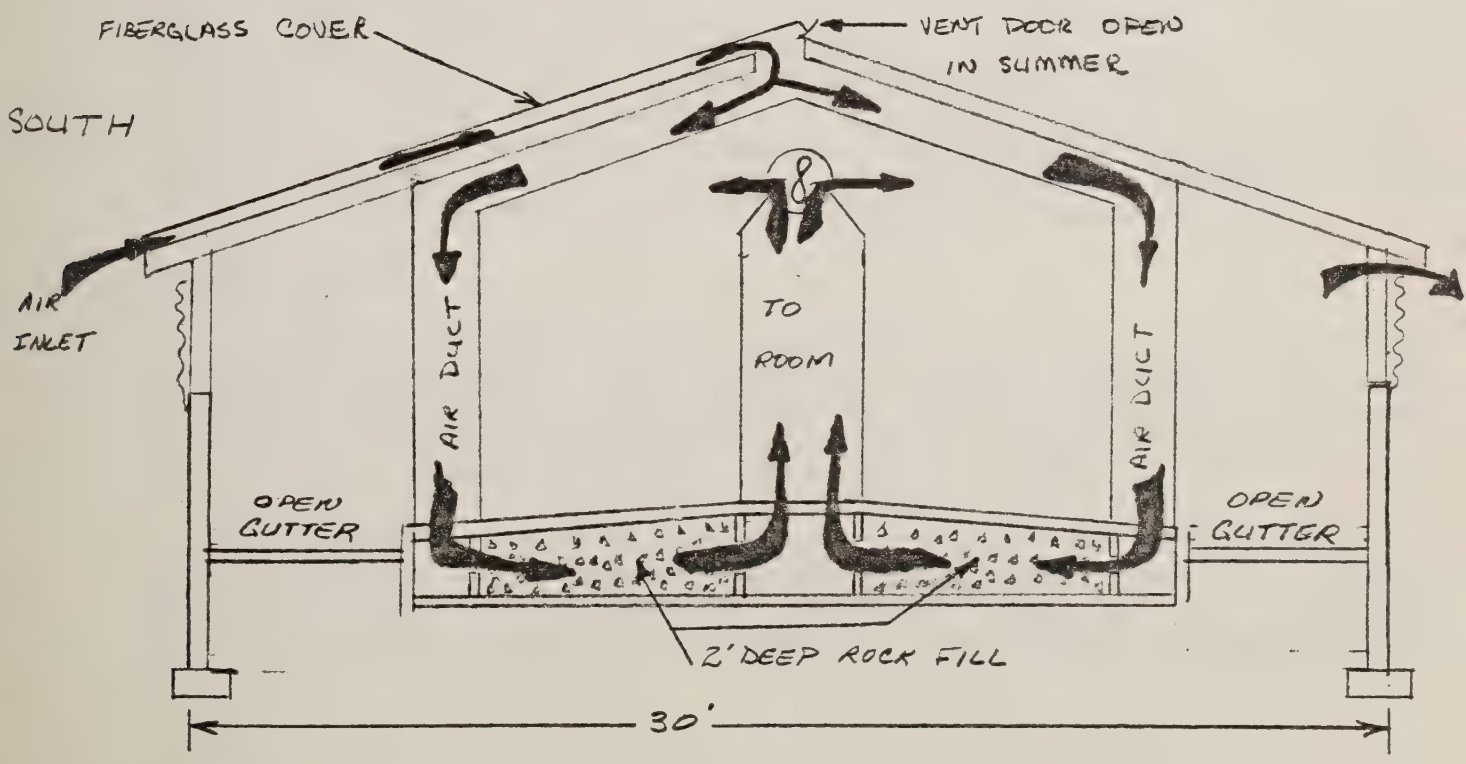
55% tax credit (25% Federal + 30% State)
$20 per square meter salvage value
10 year economic life
$0.15/liters LPG initial fuel cost
10% fuel price inflation
7% general inflation
25% tax bracket

The poor economic return from this collector is not caused by poor system performance, but rather by oversizing of the system relative to the buildings supplemental heat demand. A great deal of collected solar energy did not save fuel because there was no demand for fuel. The excess solar energy did maintain the building's temperature above the desired minimum temperature much of the time and this may have provided additional economic benefit through improved swine performance. However, it was impossible for us to quantify this benefit.

LEON HOBSON, ERIE, KANSAS



PLAN VIEW



CROSS SECTION

Dave Hund Demonstration

Dave Hund
Paxico, KS 66526



Building:

The building size is 36 ft. x 104 ft. and houses 33 farrowing crates, a 32 ft. x 36 ft. nursery, and a utility room. The main frame of the building is constructed with 2 x 6 stud walls with 6 inches of fiberglass insulation. Above the ceiling 10 inches of cellulose insulation was installed. The exterior shell of the building is enameled metal and the interior walls and ceiling are 1/2 inch exterior grade plywood. The floor of the building is total slatted stainless steel with a pit below to store manure. Supplemental heat is supplied by a 60,000 BTU/hr non-vented propane furnace in each room.

Solar Collector:

The solar collector consists of a 64 ft. x 7 ft. solar wall for the farrowing room and a 32 ft. x 7 ft. solar wall for the nursery room. This solar wall, developed at Kansas State University, consists of 2 fiberglass layers supported in front of a massive concrete block wall. Details for construction of the solar collector are given on page 5 of this report.

Fans which are installed in exhaust chimneys on the north side of the building regulate the airflow through the building. These fans cause a vaccum which induces air to flow between the fiberglass covers, and then through the 3/16 inch vertical cracks in the block wall. The blocks then temper the air

before it enters the farrowing or nursery rooms. Air withdrawal from the room is accomplished by drawing the air through the slats into the pit area and then proceeding to the chimney where it is exhausted vertically. The vertical chimney is to reduce wind pressures on fans and for natural ventilation if fans fail.

The cost of both the 7 ft. x 64 ft. and the 7 ft. x 32 ft. collectors was $2,000 for material and $1,650 for labor for a total cost of $3,650.

Projected Typical Annual Performance:

Minimal measured performance data were available for this building because the data logger at this installation failed several times. However, on our visits to the site, we observed that the building and solar collector operated nearly continuously. We used our knowledge of this building's design, construction, and operation to determine parameters for simulation of the building's performance.

The simulation of the farrowing room used a continuous minimum ventilation rate of 51 m^3/h-stall (30 cfm/stall). This is the rate specified in the building design, and it is typical of farrowing houses in Kansas. This rate produces a solar collector airflow rate of 45 kg/m^2 -h (2.0 cfm/ft^2). The furnace was set at 25 C (77 F) in the farrowing room. The simulation of the nursery room utilized a ventilation rate of 8.5 m^3/h-pig (5.0 cfm/pig) and a furnace setting of 27 C (80 F). These values are based on our observations during two winters.

Once the operational parameters were determined, the procedure for projecting typical performance of the KSU Solar Walls on this building was as described on page 3. Long-term monthly mean temperatures for northcentral Kansas were used in the building simulation, and 'typical meteorological year' data for Omaha, NE was used for simulation of solar collector performance. The results for the farrowing room are presented in Table H1 and those for the nursery are in Table H2.

Table H1. Typical Monthly Performance of the Hund Solar-Assisted Swine Farrowing Room

Month	Collected[1] Solar mJ/m^2	Collection Efficiency %	Heat[2] Demand mJ/m^2	Energy Saved mJ/m^2	Fuel Saved l/m^2	Solar Fraction %
Jan.	259	63	866	293	14.0	34
Feb.	250	59	649	270	12.9	42
Mar.	217	54	518	225	10.7	43
Apr.	156	50	250	133	6.3	53
May	145	46	100	72	3.4	72
Sep.	204	58	92	65	3.1	71
Oct.	256	62	290	179	8.5	62
Nov.	220	62	453	210	10.0	46
Dec.	206	63	765	237	11.3	31
Annual	1910	58	3980	1680	80.2	42

1. Collected solar energy is from simulated performance using Omaha, Nebraska data and 45 kg/m^2-h collector airflow rate.
2. Supplemental heat demand calculated using northcentral Kansas temperature data. All energy quantities stated per square meter of solar collector.

Table H2. Typical Monthly Performance of the Hund Solar-Assisted Swine Nursery

Month	Collected[1] Solar mJ/m^2	Collection Efficiency %	Heat[2] Demand mJ/m^2	Energy Saved mJ/m^2	Fuel Saved l/m^2	Solar Fraction %
Jan.	259	63	1400	315	15.0	23
Feb.	250	59	905	285	13.6	31
Mar.	217	54	460	208	9.9	45
Apr.	156	50	150	97	4.6	65
Oct.	256	62	80	55	2.6	69
Nov.	220	62	320	176	8.4	55
Dec.	206	63	1130	255	12.1	23
Annual	1560	59	4450	1360	65.0	31

1. Collected solar energy is from simulated performance of the KSU Solar Wall using Omaha, Nebraska TMY data and 45 kg/m^2-h collector airflow rate.
2. Supplemental heat demand calculated using northcentral Kansas temperature data. All energy quantities stated per square meter of solar collector

In a typical year we predict that the KSU Solar Wall on the farrowing room saves 1680 mJ per square meter (148,000 Btu/ft^2) and that the collector on the nursery saves 1360 mJ per square meter (120,000 Btu/ft^2). For both collectors, this energy is equivalent to 4680 liters (1240 gal) of LPG.

Economic Feasibility Analysis:

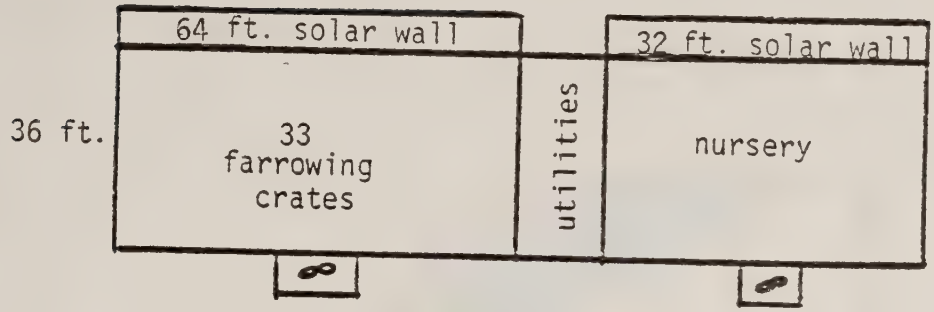
The Hund swine building is heated by two KSU Solar Walls and non-vented space heaters fueled by LPG. Assuming the space heaters are 90% efficient, the projected typical annual fuel saved by the two collectors is 74.9 liters per square meter (1.84 gal/ft^2). This is the average for both collectors. The two solar collector-storage units on this building had a total installed cost of $58.44 per square meter ($5.43/ft^2). At this cost and fuel savings rate, a life-cycle economic analysis using the parameters in the following list shows that these solar units will pay for themselves in saved fuel in ten years and provide an inflation-adjusted, after-tax annual return of over 26%. This very high rate-of-return is a result of good collector performance and very low installed cost. These solar collector-storage units would provide very good return even without solar tax credit incentives.

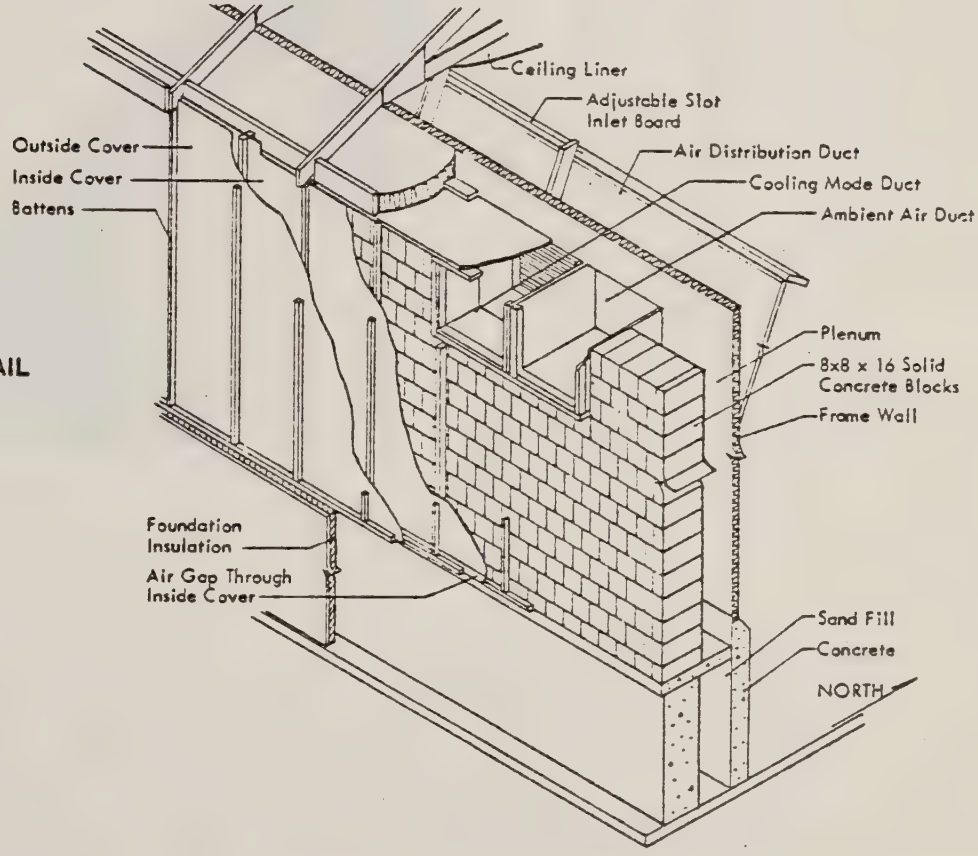
Economic Parameters in Analysis

55% tax credit (25% Federal + 30% State)
$20 per square meter salvage value
10 year economic life
$0.15/liters LPG initial fuel cost
10% fuel price inflation
7% general inflation
25% tax bracket

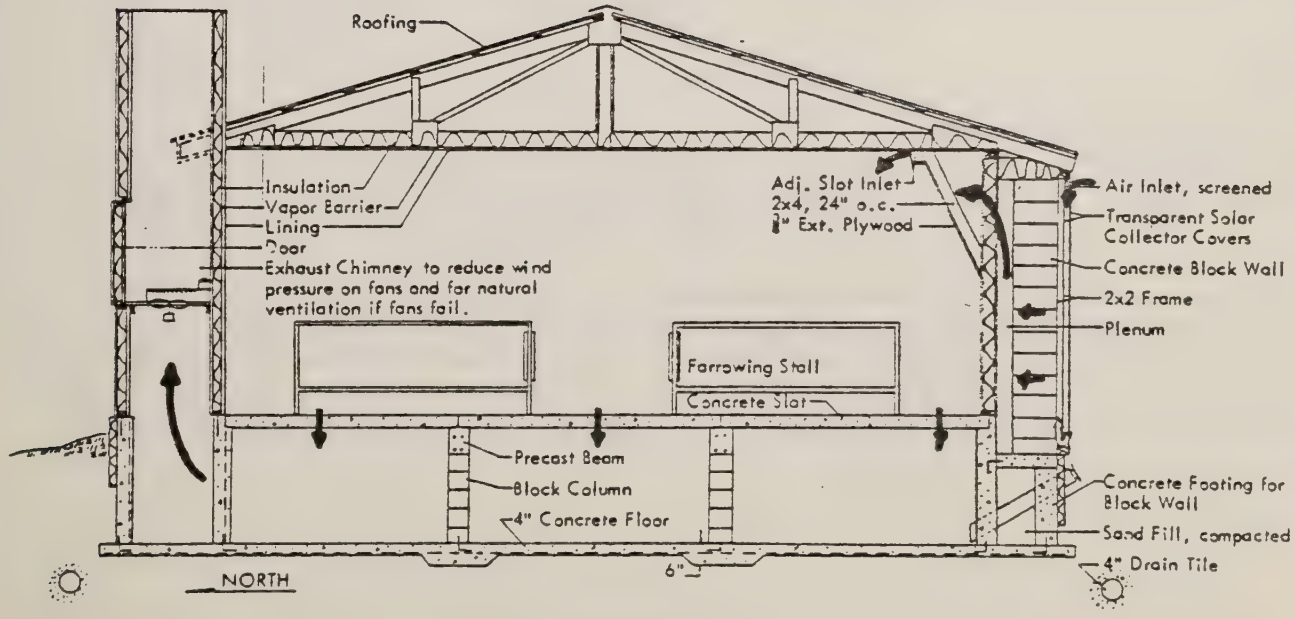
The 26% annual return is significantly higher than most producers would consider necessary for an investment with the minimal risk of the solar walls. Therefore, if it were physically practical, these collectors could have been built much larger, as much as twice as large, and significantly more fossil fuel could have been saved. This would provide more optimal use of the producers capital.

DAVE HUND, PAXICO, KANSAS





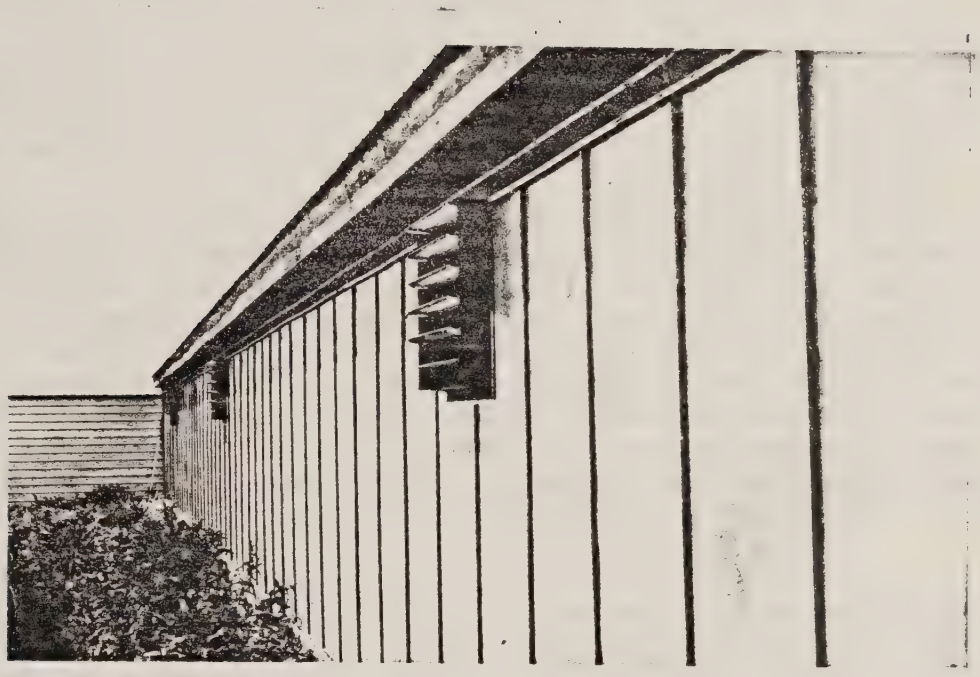
SOLAR WALL DETAIL



CROSS SECTION

Dale Keesecker Demonstration

Dale Keesecker
Washington, KS 66968



Building:

The building is a 36 ft. x 96 ft. structure which houses 3 nursery rooms. The main frame of the building is constructed with 2 x 4 stud walls with 3 1/2 inches of fiberglass insulation. Above the ceiling 10 inches of cellulose insulation was installed. The exterior shell of the building is enameled metal and the interior walls and the ceiling are 1/2 inch exterior grade plywood. The floor of the building is total slatted stainless steel with a pit below to store manure. Supplemental heat is proveded by a 60,000 Btu/hr non-vented propane furnace in each room.

Solar Collector:

On the south side of the building a solar wall was installed. This solar wall, developed at Kansas State University, consists of 2 fiberglass layers supported in front of a massive concrete block wall. Details for construction of the solar collector are given on page 5 of this report.

Fans which are installed in an exhaust chimney on the north side of the building regulate the airflow through the building. These fans cause a vaccum which induces air to flow between the fiberglass covers, and then through the 3/16 inch vertical cracks in the block wall. The blocks then temper the air before it enters the nursery rooms. All three nursery rooms draw air from the



full-length plenum behind the concrete block wall. Therefore, the entire solar collector storage unit can provide heat to any combination of rooms which require heat. Air withdrawal from the room is accomplished by drawing the air through the slats into the pit area and then proceeding to the chimney where it is exhausted vertically. The vertical chimney is to reduce wind pressures on fans and for natural ventilation if fans fail.

The size of the collector is 7 ft. x 96 ft. long. The collector cost was $5,420 or $8.07 per sq. ft.

Measured Performance:

The solar collector-storage unit on this building operated continuously and satisfactorily to preheat ventilating air throughout the data collection period. The only problem observed with this unit was over-ventilation of the collector, especially during mild weather. The problem was an error in operation, not design. Shutters were installed in this unit to allow ventilation air in excess of the required minimum to by-pass the collector and enter the building directly. However, controls for these shutters were never installed and therefore all ventilation air was drawn through the collector. The high airflow rate made the heat storage capacity very ineffective and caused a great deal of solar energy to enter the building during the afternoon hours when it was not needed.

This problem is illustrated well by the performance results for the first period in Table K1 when the airflow through the solar collector was 129 kg per square meter per hour (5.9 cfm/ft^2-hr), about three times the rate we recommended. During this period, less than half of the collected solar energy was effective in saving fuel. Also, at this very high flow rate, a great deal of fan energy is required to move the air through the solar collector-storage unit. For the overall period of data collection, 81 days, 70% of the collected solar energy was used to save fossil fuel.

Table K1. Measured Performance of the Keesecker Solar-Assisted Swine Nursery

Time Period	Amb. Temp. °C	Solar[1] Temp. °C	Bldg. Temp. °C	Flow[2] Rate kg/m^2-h	Coll.[3] Energy mJ/m^2	Heat Demand mJ/m^2	Energy Saved mJ/m^2	Fuel[4] Saved l/m^2	Solar Frac. %
11/12-12/7	2.2	5.4	23.9	129.0	237	381	115	5.48	30
1/9-1/31	-0.5	4.8	19.6	60.7	158	553	132	6.29	24
2/9-2/28	5.6	10.4	28.9	45.1	94	497	93	4.43	19
3/1-3/16	5.6	11.4	28.8	66.6	142	194	103	4.90	53
Totals 81 days	2.9	7.5	24.8	79.2	631	1630	443	21.10	27

1. Temperature of air leaving the solar collector-storage unit.
2. Airflow rate through solar collector-storage unit.
3. All energy quantities are stated per square meter of installed collector surface area.
4. Liquid petroleum gas equivalent (backup fuel) calculated at 90% of lower heating value (21 mJ per liter).

Projected Typical Annual Performance:

Using the measured performance results for this building, we developed a regression equation to predict the building's demand for supplemental heat as a function of the furnace setpoint temperature and the daily average outside air temperature. The prediction equation is:

$$\text{Suppl. Heat Demand} = 4.22(t_f - t_o) - 71.5 \quad \frac{\text{mJ}}{\text{m}^2\text{-day}} \qquad \text{Eq. K1}$$

where: t_f = furnace setpoint, ^oC
t_o = outside air temp., ^oC.

This prediction equation is only approximate. The slope of the equation is governed by the ventilation rate, which can vary considerably. The intercept represents the heat generated in the building and it depends on the number and size of the pigs in the building. However, this best-fit equation does provide us a method to project the typical annual heating demand of this building by using long-term average ambient temperature data.

Using the supplemental heat prediction equation with long-term temperature data for Manhattan, Kansas (56 miles from the building site), we predict the typical annual supplemental heat demand of this building is 3044 mJ per square meter (268,000 Btu/ft^2) of solar collector. Supplemental heat is needed from November through March. The supplemental heat required during the 81 days of monitored performance, 1625 mJ/m^2 (143,000 Btu/ft^2), thus represents somewhat over half of the typical winter's requirement.

We believe the solar collector performance during the monitored period is representative of its annual performance under the current operational scheme and that the typical annual fuel saved by the solar collector is approximately 30% of the typical annual demand. So, typical annual fuel savings equals approximately 910 mJ per square meter (80,200 Btu/ft^2) of solar collector.

Projected Typical Annual Performance with Corrected Airflow Rate:

As we mentined, significant amounts of collected solar energy did not save fuel in the Keesecker swine nursery because the collector was overventilated. Therefore, we also projected typical annual performance using the design airflow rate of approximately 45 kg/m^2 - h (2 cfm/ft^2 - h). Annual performance was determined as described on page 3 of this report. Omaha, Nebraska data was used for solar energy calculations. The results appear in Table K2. Fuel saved exceeds the collected solar energy during cold periods because the solar wall also reduces heat loss through the south wall and foundation. The results illustrate quite well the penalty paid by overventilation of the collector-storage unit. With proper airflow rate, the projected fuel savings is 22% higher than as currently operated, and solar fraction rises from 30 to 37%. Installation of the controls for the by-pass air shutters would be a very worthwhile and cost effective investment.

Another important point brought out by the results in Table K2 is the shortness of the heating season for this building. This means a large amount of solar energy which can be collected during the autumn months cannot be utilized by the building. We estimate that in excess of 460 mJ (22 liters LPG

equivalent) could be collected per square meter of solar collector and utilized for grain drying. This would greatly enhance the economic return on this solar collector.

Table K2. Typical Monthly Performance of the Keesecker Solar-Assisted Swine Nursery

Month	Collected[1] Solar mJ/m^2	Collection Efficiency %	Heat[2] Demand mJ/m^2	Energy Saved mJ/m^2	Fuel Saved l/m^2	Solar Fraction %
Jan.	259	63	1160	329	15.7	28
Feb.	250	59	702	285	13.6	41
Mar.	217	55	203	163	7.8	80
Nov.	220	62	85	81	3.9	96
Dec.	206	63	894	258	12.3	29
Annual	1152	60	3044	1116	53.1	37

1. Collected solar energy is from simulated performance using Omaha, Nebraska data and 45 kg/m^2-h collector airflow rate.
2. Supplemental heat demand calculated by Equation K1 using Manhattan, Kansas temperature data. All energy quantities stated per square meter of solar collector.

Economic Feasibility Analysis:

Supplemental heat for this swine nursery is provided by the KSU Solar Wall unit and non-vented space heaters fueled by liquid petroleum gas. Assuming these space heaters have 90% combustion efficiency, the typical annual fuel saved by the solar collector, as currently operated, is 43.3 liters of LPG per square meter (1.06 gallon/ft^2) of collector. This solar collector-storage unit had a total installed cost of $87 per square meter ($8 per square foot). At this cost, and using the economic parameters listed below, a life-cycle economic analysis shows this solar unit will pay for itself in 10 years and provide a 6% inflation-adjusted, after-tax return on the invested capital. This is very acceptable economic performance for must swine producers.

If controls are added for the by-pass shutters to control collector airflow rate, we project annual fuel savings would rise to 53 liters of LPG per square meter (1.30 gallon/ft^2) of collector. The collector would then provide a ten year pay-out with 9% inflation-adjusted, after-tax return on the investment.

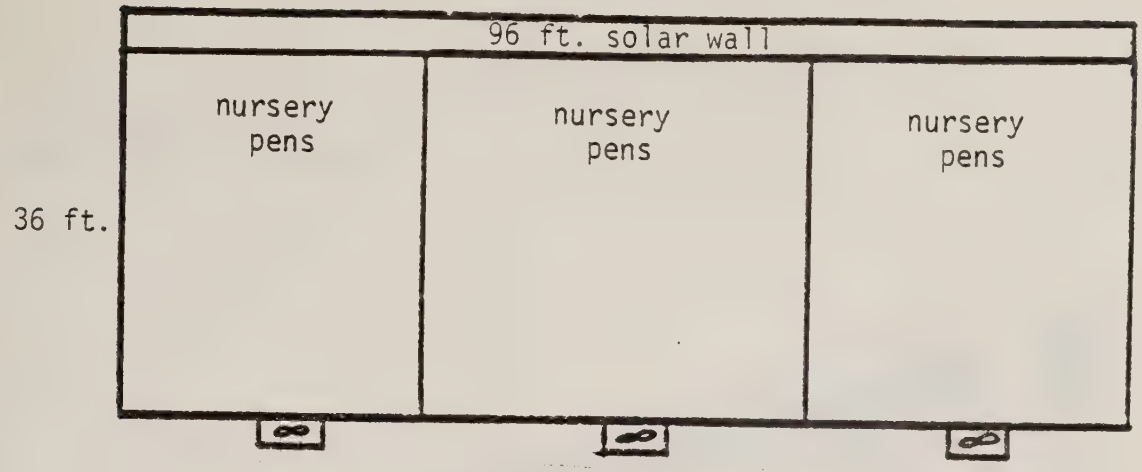
Economic Parameters in Analysis

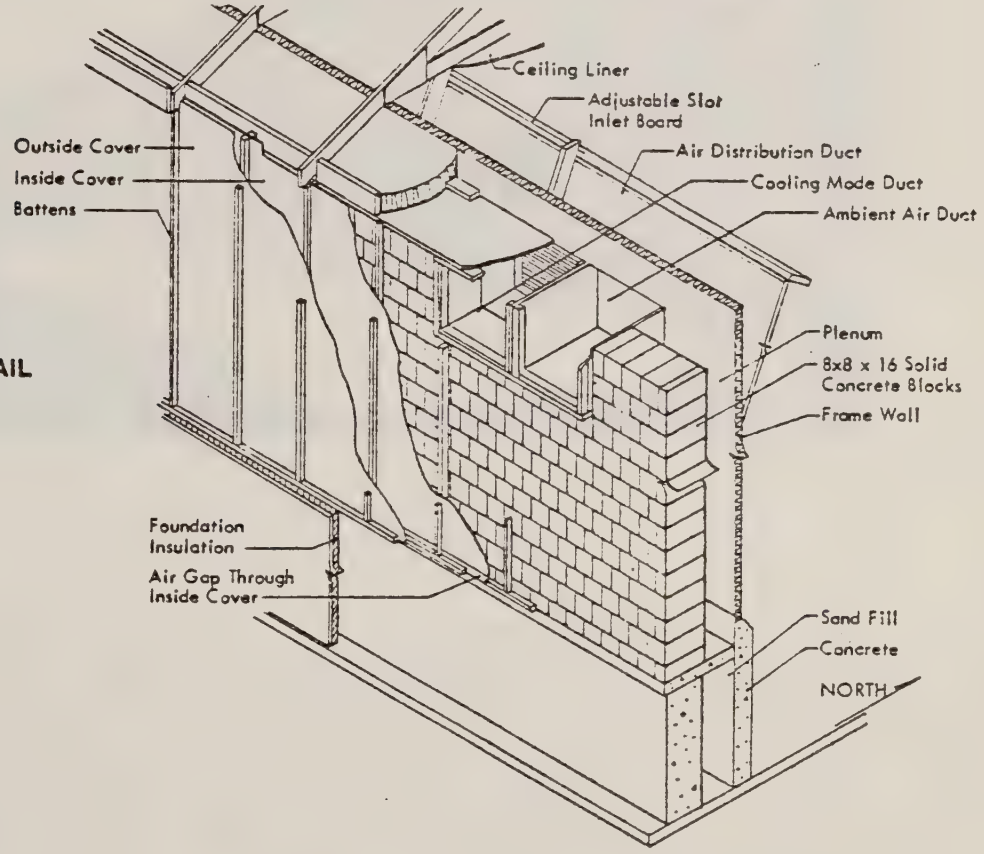
55% tax credit (25% Federal + 30% State)
$20 per square meter salvage value
10 year economic life
$0.15/liters LPG initial fuel cost
10% fuel price inflation
7% general inflation
25% tax bracket



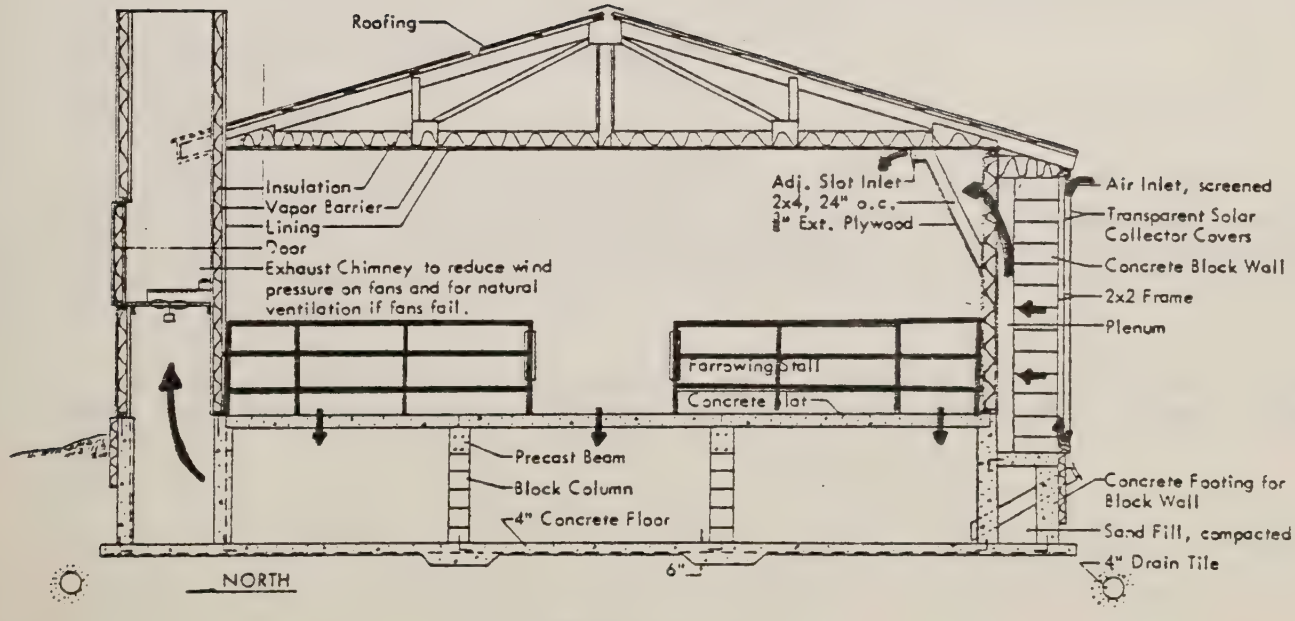
Farm visits to the solar collectors usually involve several friends.

DALE KEESECKER, WASHINGTON, KANSAS





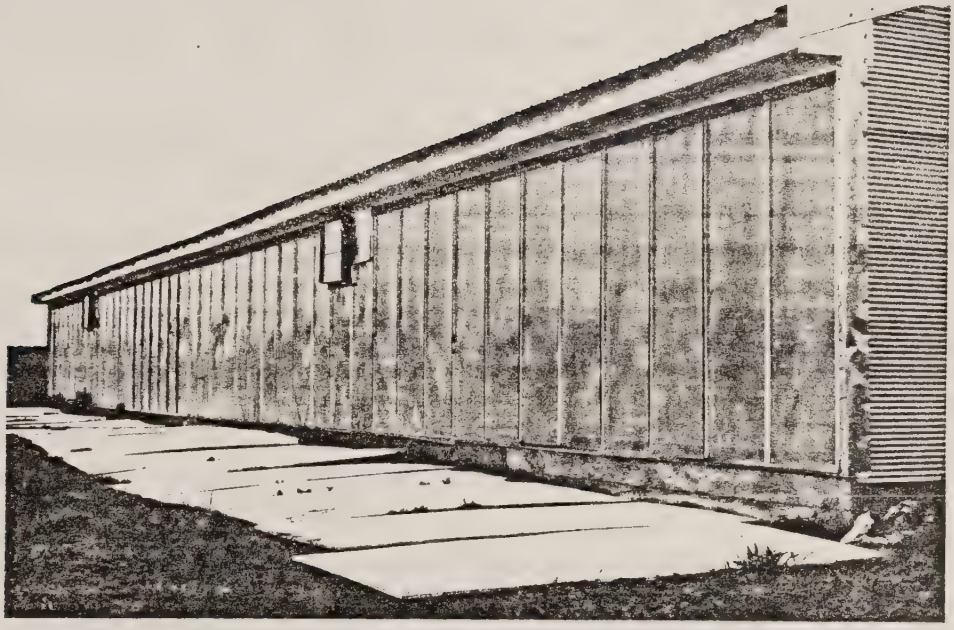
SOLAR WALL DETAIL



CROSS SECTION

Leon Pifer Demonstration

Leon Pifer
Washington, KS 66968



Building:

The building is a 26 ft. x 88 ft. wood frame structure which includes; a 46 ft. x 24 ft. farrowing room with crates, a 32 ft. nursery, and an 8 ft. x 24 ft. feed and utility room between the farrowing and nursery rooms. The sidewalls are 8 ft. high constructed with 2 x 6 inches with 6 inches of fiberglass insulation and a polyethylene vapor barrier. The ceiling has 8 inches of cellulose insulation over it. The exterior shell of the building is enameled metal and the interior walls and ceiling are 1/2 inch exterior grade plywood. The floor of the building is total slatted stainless steel with a pit below to store manure. Supplemental heat is supplied by a 60,000 BTU/hr non-vented propane furnace in each room.

Solar Collector:

On the south side of the building a solar wall was installed the full length of the building. This solar wall, developed at Kansas State University, consists of 2 fiberglass layers supported in front of a massive concrete block wall. Details for construction of the solar collector are given on page 5 of this report.

Fans which are installed in an exhaust chimney on the north side of each room regulate the airflow through the building. These fans cause a vaccum



which induces air to flow between the fiberglass covers, and then through the 3/16 inch vertical cracks in the block wall. The blocks then temper the air before it enters the farrowing or nursery room. Both the farrowing room and nursery room draw air from the full-length plenum behind the concrete block wall. Thus, the solar collector-storage unit can be utilized by either or both rooms depending on their heat demand. Air withdrawal from the room is accomplished by drawing the air through the slats into the pit area and then proceeding to the chimney where it is exhausted vertically. The vertical chimney is to reduce wind pressures on fans and for natural ventilation if fans fail.

The solar collector is 88 ft. long and 6 ft. 10 inches high with a total area of 600 sq. ft. Collector cost was $5,025 or $8.38 per sq. ft.

Measured Performance:

The Pifer solar-assisted swine building includes both a nursery room and farrowing room separated by a small feed and utility room. A KSU Solar Wall runs along the entire south face of the building and both rooms draw ventilating air through it. Performance data was collected only from the farrowing portion of the building. To have an accurate analysis of solar collector performance, it was necessary to determine the area of solar collector normally utilized by the farrowing room.

By analyzing the performance of the solar collector during two very clear days, for which solar insolation can be accurately estimated, we determined that the farrowing room was utilizing approximately 60% of the total collector area. This is based on the assumption of uniform airflow through the collector. We analyzed all the performance data using this constant area. However, the collector area utilized by the farrowing room could have varied somewhat due to differences in relative airflow between the farrowing room and nursery.

We provide a summary of the measured performance results for the farrowing room in Table P1. The solar collector-storage unit operated continuously during this period to preheat the incoming ventilation air. During the 33 days of measured performance, the solar wall raised incoming ventilating air temperature an average 13.1 ^{o}C and provided the building 260 mJ of fuel saving per square meter of exposed collector. This figure does not include the fuel saved by reducing the heat lost from the buildings south wall and foundation. With this energy included, fuel savings would increase about 10%.

The airflow rate through the solar collector was very stable throughout the data collection period, averaging 31.0 kg/m^{2}-h. This airflow rate provided both good solar collection efficiency (55%) and adequate storage of the energy throughout the day to increase utilization of the solar energy. During this period, which includes most of the coldest portion of the year, 90% of the collected solar energy was utilized in the building to conserve fossil fuel. This ratio will certainly decrease somewhat for a full-heating season, but it still seems very acceptable.

Table P1. Measured Performance of the Pifer Solar-Assisted Swine Farrowing Room

Time Period	Amb. Temp. °C	Solar[1] Temp. °C	Bldg. Temp. °C	Flow[2] Rate kg/m²-h	Coll.[3] Energy mJ/m²	Heat Demand mJ/m²	Energy Saved mJ/m²	Fuel[4] Saved m³/m²	Solar Fraction %
11/19-11/29	2.8	16.8	29.6	34.0	109	123	95	3.23	77
12/18-12/31	-2.7	6.9	30.0	30.8	82	218	82	2.80	38
1/1-1/6	-1.8	11.4	30.0	30.0	49	88	49	1.66	55
1/22-1/27	5.6	21.1	32.4	26.7	48	37	34	1.17	93
Totals 33 days	0.4	12.7	30.2	31.0	288	466	260	8.86	56

1. Temperature of air leaving the solar collector-storage unit.
2. Airflow rate through solar collector-storage unit.
3. All energy quantities are stated per square meter of installed collector surface area.
4. Natural gas equivalent (backup fuel) calculated at 90% of the lower heating value (29.3 mJ/m^3).

Projected Typical Annual Performance:

Using the measured performance results, we developed an equation to predict the farrowing rooms demand for supplemental heat as a function of furnace set point temperature and average daily outside air temperature. The prediction equation is:

$$\text{Suppl. Heat Demand} = 0.813\ (t_f - t_o) - 7.78 \quad \frac{mJ}{m^2\text{-day}} \qquad \text{Eq. P1}$$

Where: t_f = furnace setpoint, °C
t_o = outside air temp., °C

This equation is an approximation of actual building supplemental heat demand, since both constants in the equation vary depending on ventilation rate and animal size. Based on the results of computer simulations of farrowing house energy demand using hourly weather data, we feel Equation P1 gives a conservative estimate of demand.

Using Equation P1 with long-term average temperature data for Manhattan, Kansas (90 km from building site) and a furnace setpoint temperature of 27.5°C (the value that prevailed throughout the measured period), we predicted the typical monthly heat demand in the farrowing room. These values were used with simulated typical-year performance of a solar collector-storage unit at Omaha, Nebraska to project typical monthly and annual performance of the Pifer farrowing room. The method of projecting typical annual performance is described fully on page 3 of this report.

The projected typical performance of the Pifer swine farrowing room is shown in Table P2. The heating season for this building stretches over an eight month period; making it possible to supply a large amount of solar energy to the building. The fuel saved by the solar collector exceeds the collected solar energy during some months because the energy saved by reducing

heat loss from the south side of the building is included in the fuel savings, as it should be. In a typical year, we project the solar collector will save 1234 mJ of fossil fuel heat per square meter (1.44 gal. LPG/ft^2) of collector. This represents 58% of the total building supplemental heat requirement.

Table P2. Typical Monthly Performance of the Pifer Solar-Assisted Swine Farrowing Room

Month	Collected[1] Solar mJ/m^2	Collection Efficiency %	Heat[2] Demand mJ/m^2	Energy Saved mJ/m^2	Fuel Saved l/m^2	Solar Fraction %
Jan.	232	56	498	250	11.9	50
Feb.	224	53	383	226	10.7	59
Mar.	195	49	313	191	9.0	61
Apr.	142	46	119	99	4.7	84
May	134	43	7	7	.3	94
Oct.	238	57	80	71	3.3	90
Nov.	199	56	281	187	8.9	67
Dec.	184	56	446	202	9.6	45
Total	1548	53	2130	1230	58.5	58

1. Collected solar energy is from simulated performance of the KSU Solar Wall using Omaha, Nebraska TMY data and 28.8 kg/m^2-h collector airflow rate.
2. Supplemental heat demand calculated by Eq. 2 using Manhattan, Kansas temperature data. All energy quantities stated per square meter of solar collector

As mentioned previously, only about 60% of the solar collector on this building serves the farrowing room which we monitored. The remaining 40% supplies heat to the swine nursery. The supplemental heat demand and solar fuel savings will not be the same for the two rooms. Based upon the data collected at the Keesecker swine nursery, which is of nearly identical construction, we believe the Pifer swine nursery required negligible suplemental heat during April, May, and October. Assuming fuel savings per square meter of solar collector are equal for the farrowing room and nursery room during the remaining five months, we project that fuel saved in the nursery would typically be 1057 mJ per square meter of collector per year.

We project that the solar collector-storage unit on the Pifer swine confinement building (farrowing and nursery) saves 1163 MJ of fossil fuel heat per square meter of collector surface area during a typical year. Throughout the projection process, we have made conservative assumptions, and we feel this projection is a conservative value.

Economic Feasibility Analysis:

Supplemental heat for the Pifer swine building is provided by the KSU Solar Wall unit and by non-vented space heaters fueled by natural gas. Assuming these heaters utilize 90% of the lower heating value of the gas, the typical annual fuel saved by the solar collector is 39.7 m^3 of gas per square meter of solar collector. Fuel bills from the Pifer farm for the 1981-82

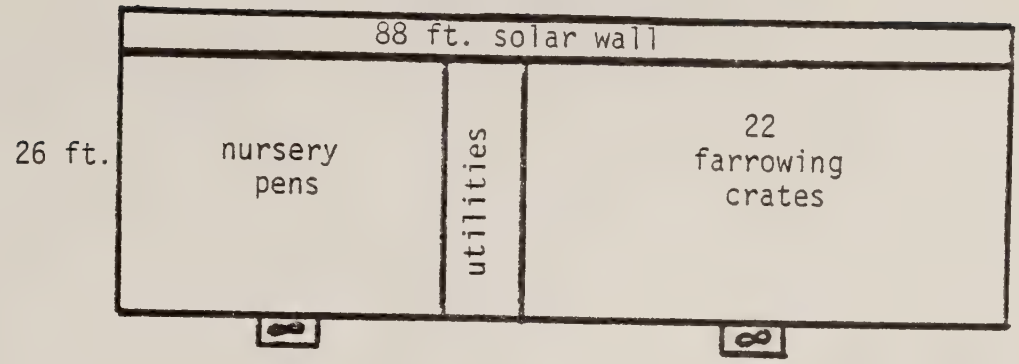
heating season showed an average unit fuel cost of $0.116 per cubic meter.

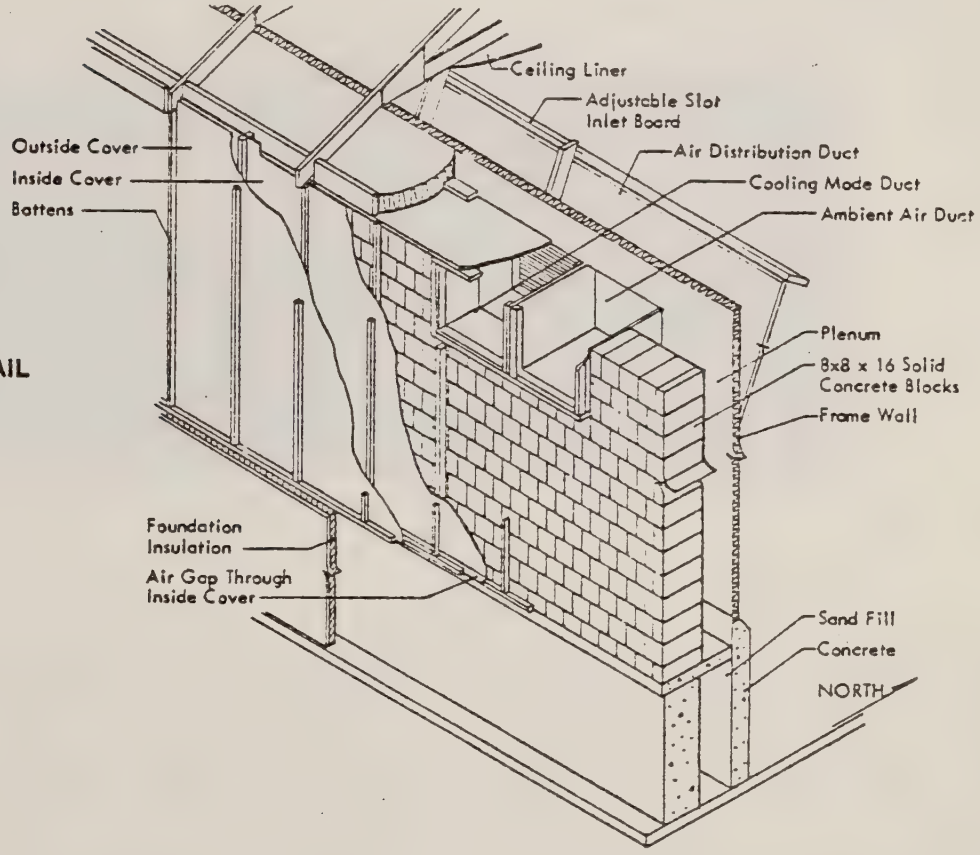
The Pifer solar collector-storage unit cost $90 per square meter installed. A life-cycle economic analysis using the stated typical annual fuel savings rate and costs along with other economic parameters stated below shows that this solar collector unit will pay for itself in ten years and provide a 1% inflation-adjusted, after-tax return on the invested capital.

This economic performance would be unacceptable to most swine producers. The poor economic performance of this collector is caused by the low cost of the fossil fuel it replaces (natural gas). The economic analysis was performed using a 10% fuel cost escalation rate and a 7% general inflation rate. If the fuel cost escalates faster than this assumed rate, which seems possible for natural gas, the economic feasibility of the solar collector will be improved.

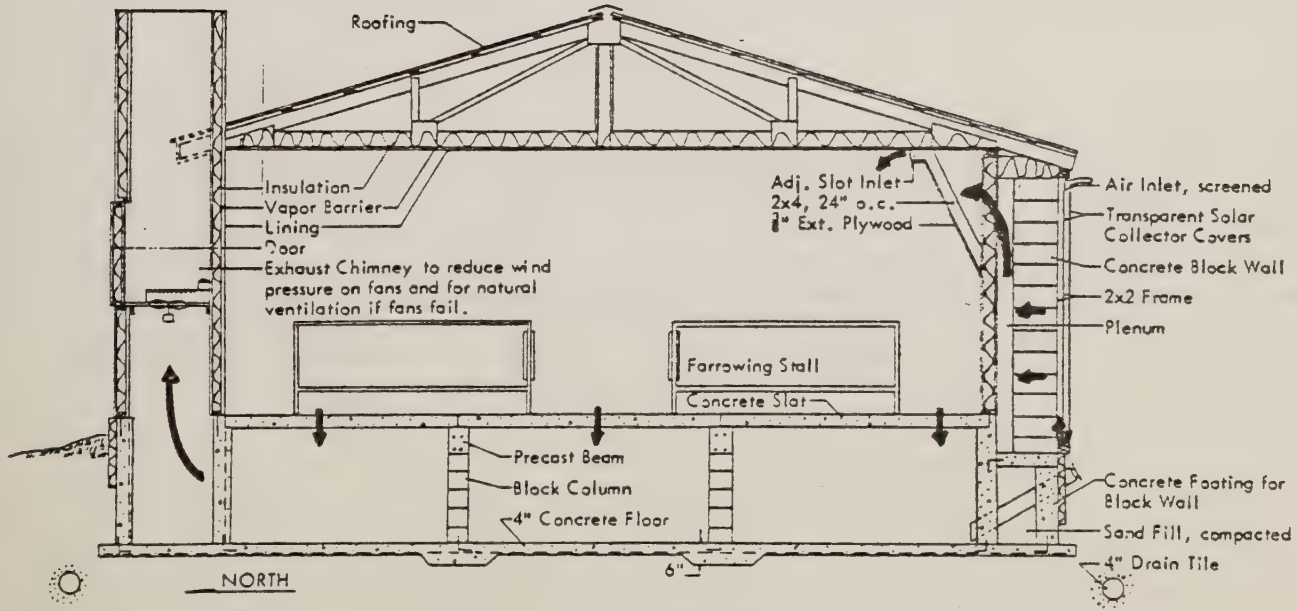
Economic Parameters in Analysis

55% tax credit (25% Federal + 30% State)
$20 per square meter salvage value
10 year economic life
$0.12/$m^3$ initial fuel cost
10% fuel price inflation
7% general inflation
25% tax bracket





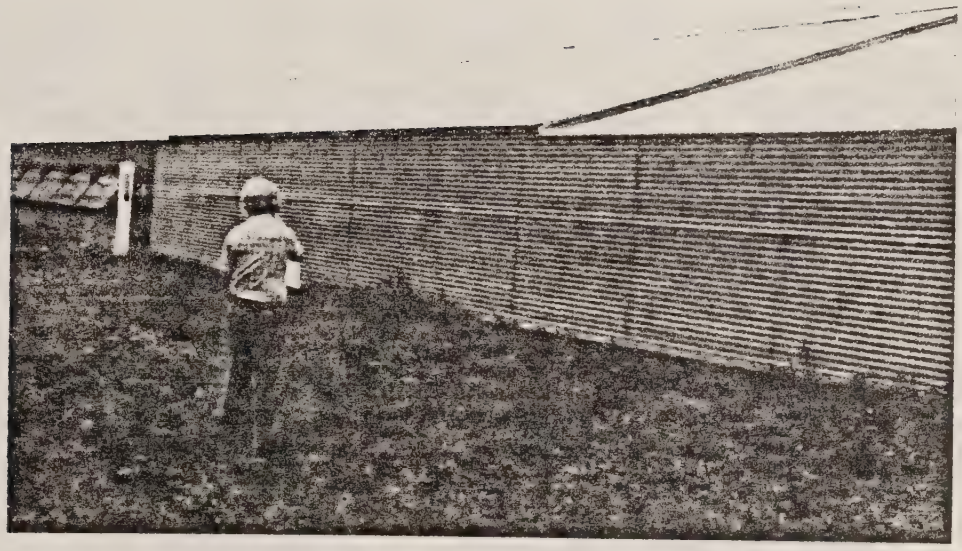
SOLAR WALL DETAIL



CROSS SECTION

Premium Pork, Inc. Demonstration

Merlin Dennis
Kensington, KS 66951



Building:

The building is 48 ft. x 102 ft. which houses 3 farrowing rooms of 12 crates each, 3 weaning nursery rooms of 12 litters each and a 48 by 30 foot grower room. The building is wood frame construction with 2 x 4 walls filled with 3 1/2 inches of fiberglass. The walls and ceiling are 1/2 exterior grade plywood. There is 9 inches of cellulose insulation above the ceiling. There is a partial slat floor in the farrowing and nursery rooms. Manure is removed from the building with flushing gutter. Supplemental heat is provided through hot water pipes suspended in the rooms. Creep heat is provided by hot water pipes imbedded in the concrete.

Solar Collector:

Solar water collectors are mounted at a 30^0 angle on the south facing side of the gable roof. There are 20 solar water collectors measuring 4 ft. x 10 ft. each. The heat from the collectors is stored in a water storage tank which measures 7 ft. x 7 ft. x 7 ft. The heat is distributed to the various rooms by copper pipe imbedded in the solid concrete portion of the farrowing and nursery pens. A boiler serves as a backup in case the water temperature falls below 120°.

The system was purchased from SUNDUIT, Inc., 281 E Jackson St., Virden, Illinois, 62690. Total cost of the system was $9,600 or $12.00 per sq. ft. of collector exposed to the sun.

Monitored Performance Results:

During the first winter, cold water was allowed to return to the hot water boiler causing the cast iron heat exchangers to crack. To solve the problem, a commercial hot water heater was installed in place of the cast iron boiler.

The return lines from the collector were installed in the attic space above the ceiling. During the summer, the attic was hot enough to deform the return plastic pipe to the extent that a complete draindown did not occur in winter. This caused freezing in the collector and plastic plumbing serving the collector. Several modifications were made to the plumbing without success. Consequently, the system operated very little and no useful performance data was gathered from the system.

Estimated Achievable Performance:

We have estimated the performance of this solar collection system that we feel is achievable if modifications and improvements were made to make it fully operational. Our estimation is based on the following assumptions; 1. Annual average collection efficiency of 40%. 2. Annual average utilization efficiency of 50%. 3. Overall annual system efficiency of 20%.

Using solar radiation data from Lincoln, Nebraska (40.9° North Latitude, the closest station) and a 30° roof slope, the following mean daily solar radiation arrives at the collector surface:

MEAN DAILY SOLAR RADIATION

Jan.	1225	Apr.	1676	Jul.	1851	Oct.	1593
Feb.	1391	May	1780	Aug.	1873	Nov.	1173
Mar.	1606	Jun.	1862	Sep.	1712	Dec.	1128

Overall mean = 1,573 BTU's per square foot per day
Annual Total = 573,962 BTU's per square foot

At 20% efficiency, 114,792 BTU's could be collected and utilized for every square foot of collector. For the total collection area of 800 square feet, 91,834,000 BTU's would be available in one year. This amount of heat is contained in 1123 gallons of propane, the equivalent of 1.40 gallons of propane per square foot of collector per year.

Economic Analysis:

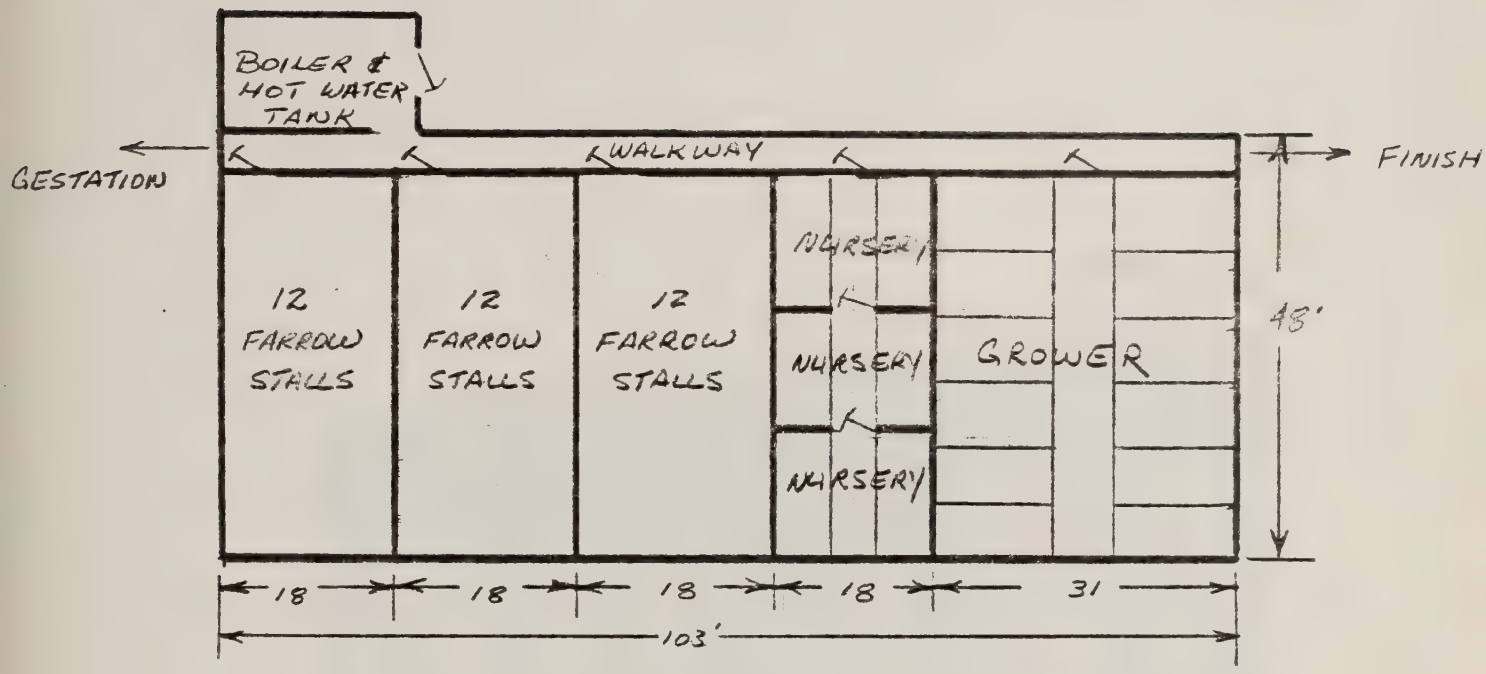
Currently the economic performance of this solar collection system is very poor due to operational problems. If improvements can be made to bring performance up to the value we feel is achievable (1.4 gal. LPG/ft^2), economic feasibility would greatly improve. With propane priced at $0.60 per gallon, the annual return would be $0.84 per square foot of collector. The rate-of-

return and economic feasibility would then depend on the initial installed cost ($12.00 per square foot) and the additional cost of the improvements and repairs, which are at this time unknown.

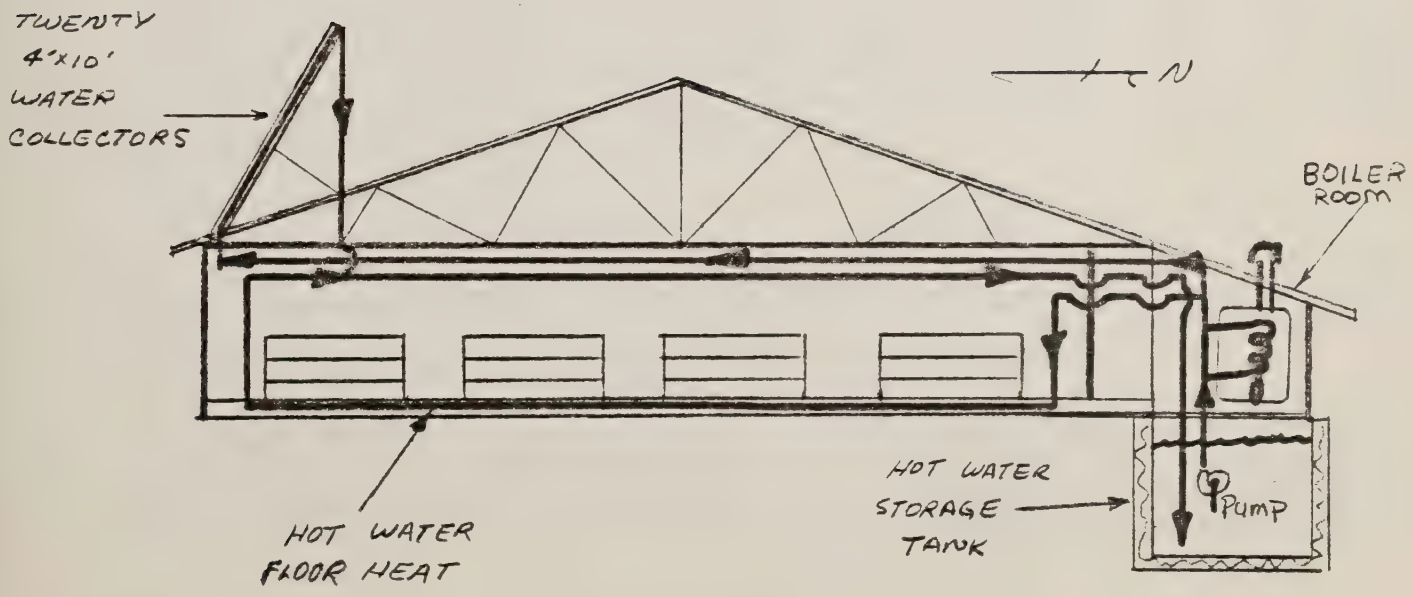


Pigs enjoying solar energy

MERLIN DENNIS, PHILLIPSBURG, KANSAS



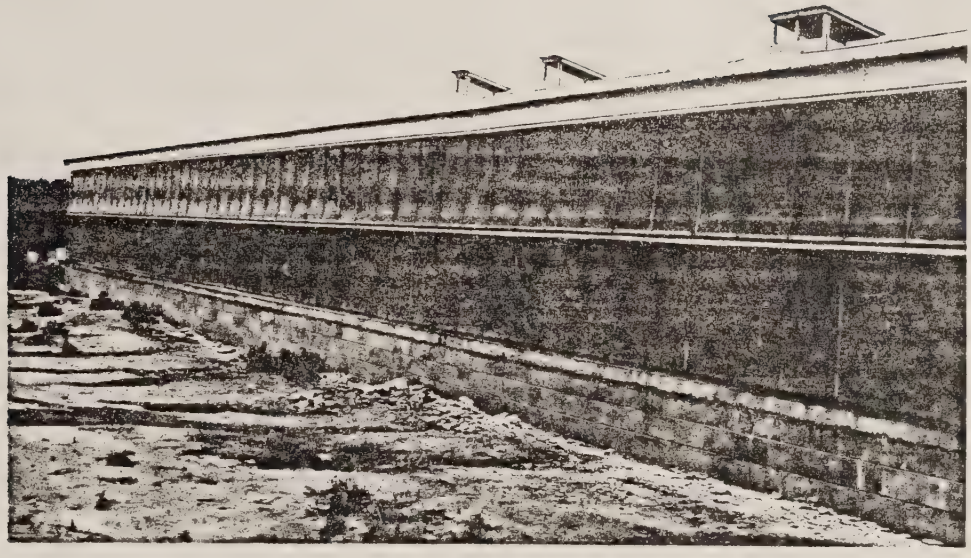
PLAN VIEW



CROSS SECTION

Valley View Farm Demonstration

Arlen Benteman
Clifton, KS 66937



Building:

The building is a 51 ft. x 112 ft. total slat nursery with 7 rooms. The main frame of the building is constructed with 2 x 4 stud walls with 3 1/2 inches of fiberglass insulation. Above the ceiling 10 inches of cellulose insulation was installed. The exterior shell of the building is enameled metal and the interior walls of the ceiling are 1/2 inch exterior grade plywood. The floor of the building is total slatted with fiberglass slats with a pit below to store manure. Supplemental heat is provided by two, non-vented, 60,000 Btu/hr LPG furnaces in the ventilation distribution duct plus a 60,000 Btu/hr non-vented furnace in each room.

Solar Collector:

On the south side of the building a solar wall was installed. This solar wall, developed at Kansas State University, consists of 2 fiberglass layers supported in front of a massive concrete block wall. Details for construction of the solar collector are given on page 5 of this report.

Fans which are installed in an exhaust chimney in each room of the building regulate the airflow through the building. These fans cause a vaccum which induces air to flow between the fiberglass covers, and then through the 3/16 inch vertical cracks in the block wall. The blocks then temper the air



before it enters the nursery rooms. All seven rooms draw air from the full-length walkway along their south side (see plan view). Air from the solar wall enters this walkway through four adjustable inlets along its length. Therefore any combination of the seven rooms which need supplemental heat can utilize the solar wall. Shutters which allow air from the walkway into each room are adjusted manually. They are gradually closed as the pigs grow and require less supplemental heat. This keeps total airflow through the collector at a reasonable rate and allows more efficient use of the available solar energy. Additional shutters in the north wall of each nursery room are opened to admit outside air to the room as the solar heated air supply is reduced. Air withdrawal from the room is accomplished by drawing the air through the slats into the pit area and then proceeding to the chimney where it is exhausted vertically. The vertical chimney is to reduce wind pressures on fans and for natural ventilation if fans fail.

The size of the collector is 7 1/2 ft. x 112 ft. long with 840 sq. ft. exposed to the sun. Collector cost was $10,675.88 or $12.71 per sq. ft.

Measured Peformance:

The solar collector-storage unit on this building continuously preheated the ventilating air for the seven nursery rooms. In this building, all air from the solar collector enters a large full-length duct where heat is added by direct-fire LPG heaters and then distributed to individual rooms. Thus all rooms draw air from the solar collector as a whole. We measured the temperature and flow rate of air from the solar collector as it entered the large duct, so we could determine total energy supplied by the collector-storage unit.

A summary of the hourly measured performance results for this installation is presented in Table B1. The building temperature was measured in the full-length distribution duct. The nursery rooms were maintained at approximately 25.5 C (78 F). This building is quite wide and therefore, the floor area, ventilating rate, and heat demand, are large compared to the solar collector area. This necessitated the use of automatic shutters to allow some ventilation air to by-pass the solar wall and enter the nursery rooms directly. The shutters maintained airflow rate through the collector at a fairly constant rate. The prevailing airflow rate, 36.5 kg/m^2-h or 1.7 cfm/ft^2, provided good collection efficiency and good energy storage (thermal lag-time).

The large building size, relative to collector size, resulted in low values of solar fraction, but high solar energy utilization. During the 71 days which were monitored, which were significantly milder than normal, 93% of all collected solar energy actually saved fuel.

Table B1. Measured Performance of the Benteman Solar-Assisted Swine Nursery

Time Period	Amb. Temp. °C	Solar[1] Temp. °C	Bldg.[2] Temp. °C	Flow[3] Rate kg/m^2 -h	Coll.[4] Energy mJ/m^2	Heat Demand mJ/m^2	Energy Saved mJ/m^2	Fuel[5] Saved l/m^2	Solar Frac. %
11/19-12/7	2.3	12.9	16.9	36.1	162	653	160	7.62	25
1/27-2/28	1.1	12.7	24.7	36.3	312	1190	269	12.80	23
3/1-3/20	5.6	16.3	21.4	37.3	194	705	193	9.20	27
Totals 71 days	2.7	13.8	21.8	36.5	668	2550	622	29.62	24

1. Temperature of air leaving the solar collector-storage unit.
2. Temperature measured in ventilating air distribution duct after some supplemental heating; room temperature is higher.
3. Airflow rate through solar collector-storage unit.
4. All energy quantities are stated per square meter of installed collector surface area.
5. Liquified Petroleum gas equivalent (backup fuel) calculated at 90% of the lower heating value (21 mJ/m^3).

Projected Typical Annual Performance:

Based upon the construction of this building and the measured operation of the building, we developed an equation to predict the buildings demand for supplemental heat. The heat demand is a function of furnace setpoint temperature and average daily outside air temperature. The prediction equation is:

$$\text{Suppl. Heat Demand} = 2.54(t_f - t_o) - 21.3 \quad \frac{\text{mJ}}{\text{m}^2\text{-day}} \qquad \text{Eq. B1}$$

where: t_f = furnace setpoint, °C
t_o = outside air temperature, °C.

This equation is only approximate, since both the slope and intercept can vary with ventilating rate, animal size, and stucking density. Equation B1 will predict the typical monthly and annual heat demand with reasonable accuracy by using long-term average ambient temperature data.

Using Eq. B1 with long-term average ambient temperature data for North-centeral Kansas and simulated solar collector performance with Omaha, NE, TMY data, we have projected typical annual performance as described on page 3 of this report. The results appear in Table B2. We used a furnace setpoint temperature of 25.5 C (78 F) and a collector airflow rate of 35 kg/m^2 -h (1.6 cfm/ft^2.

In a typical year, we predict that the KSU Solar Wall on the Benteman swine nursery saves 1665 mJ per square meter of collection surface (147,000 Btu/ft^2). For the 78.0 square meter (840 ft^2) collector, this is equivalent to 6185 liters (1634 gal) of LPG. This is 25% of the annual supplemental heat required.

Table B2. Typical Monthly Performance of the Benteman Solar-Assisted Swine Nursery

Month	Collected[1] Solar mJ/m^2	Collection Efficiency %	Heat[2] Demand mJ/m^2	Energy Saved mJ/m^2	Fuel Saved l/m^2	Solar Fraction %
Jan.	244	59	1550	310	14.8	20
Feb.	235	56	1190	290	13.8	24
Mar.	203	51	998	250	12.1	25
Apr.	147	47	352	150	7.1	43
Oct.	238	57	240	160	7.6	67
Nov.	207	58	890	255	12.1	29
Dec.	193	59	1390	250	11.9	18
Annual	1470	55	6610	1665	79.3	25

1. Collected solar energy is from simulated performance using Omaha, Nebraska data and 45 kg/m^2 -h collector airflow rate.
2. Supplemental heat demand calculated by Eq. B1 using Manhattan, Kansas temperature data. All energy quantities stated per square meter of solar collector.

Economic Feasibility Analysis:

The Benteman swine nursery is heated by the KSU Solar Wall and non-vented space heaters fueled by LPG. Assuming these space heaters are 90% efficient, the typical annual fuel saved by the solar collector is 79.3 liters per square meter (1.95 gal/ft^2); see Table B2. The solar collector-storage unit had a total installed cost of $137 per square meter ($12.71/ft^2). At this cost, and using the economic parameters in the following list, a life-cycle economic analysis shows that this solar unit will pay for itself in 10 years and provide a 9.0% inflation-adjusted, after-tax return on the invested capital.

Economic Parameters in Analysis

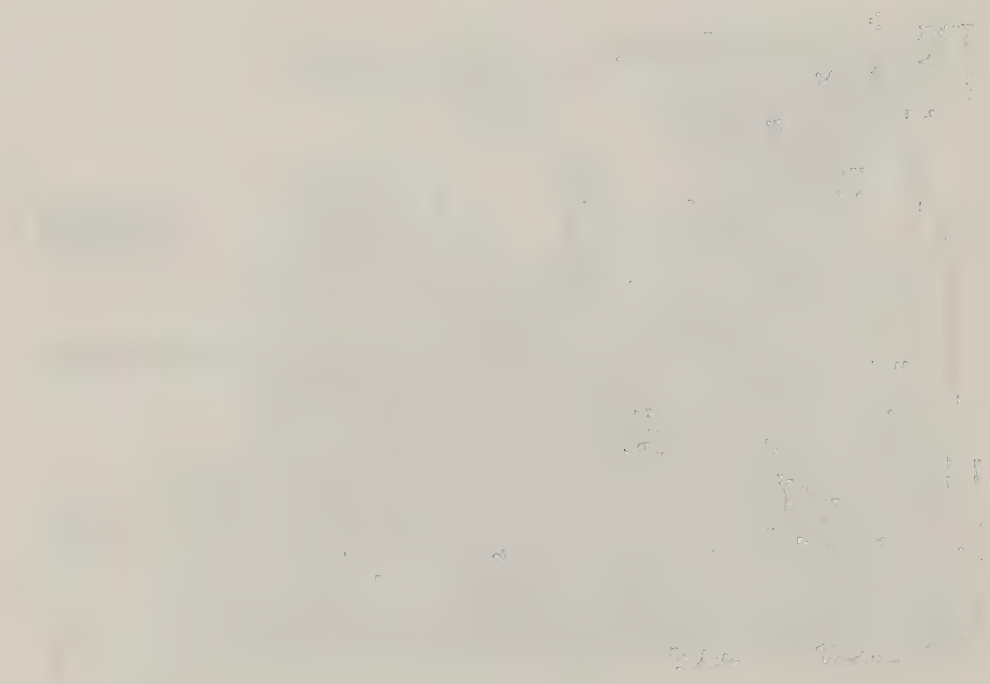
55% tax credit (25% Federal + 30% State)
$20 per square meter salvage value
10 year economic life
$0.15/liters LPG initial fuel cost
10% fuel price inflation
7% general inflation
25% tax bracket

Most swine producers would accept a significiantly lower return than 9.0% on an investment with the minimal risk that the solar collector involves. Therefore, this solar collector could have been increased in size until the diminishing marginal return lowered overall return to about 5 to 6 percent, which would still be acceptable. This would provide optimal use of the producer's available capital.

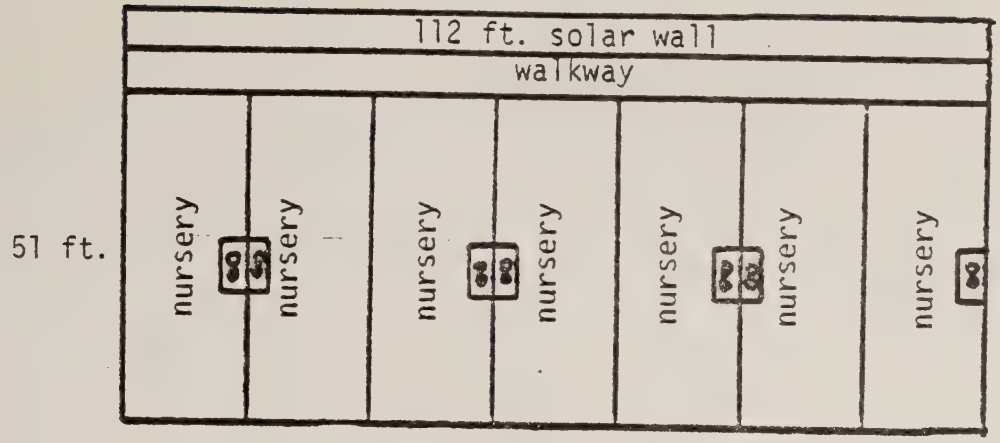
Assuming a larger collector could have been built at the same unit area cost, we predict the collector could have been sized 60% larger, 125 m^2 or 1344 ft^2. At this size, fuel saved per unit area would be only 63 liters/m^2 (1.55 gal/ft^2), but total fuel saved would increase to 7880 liters (2080 gal) of LPG. The solar fraction would then be 32%.

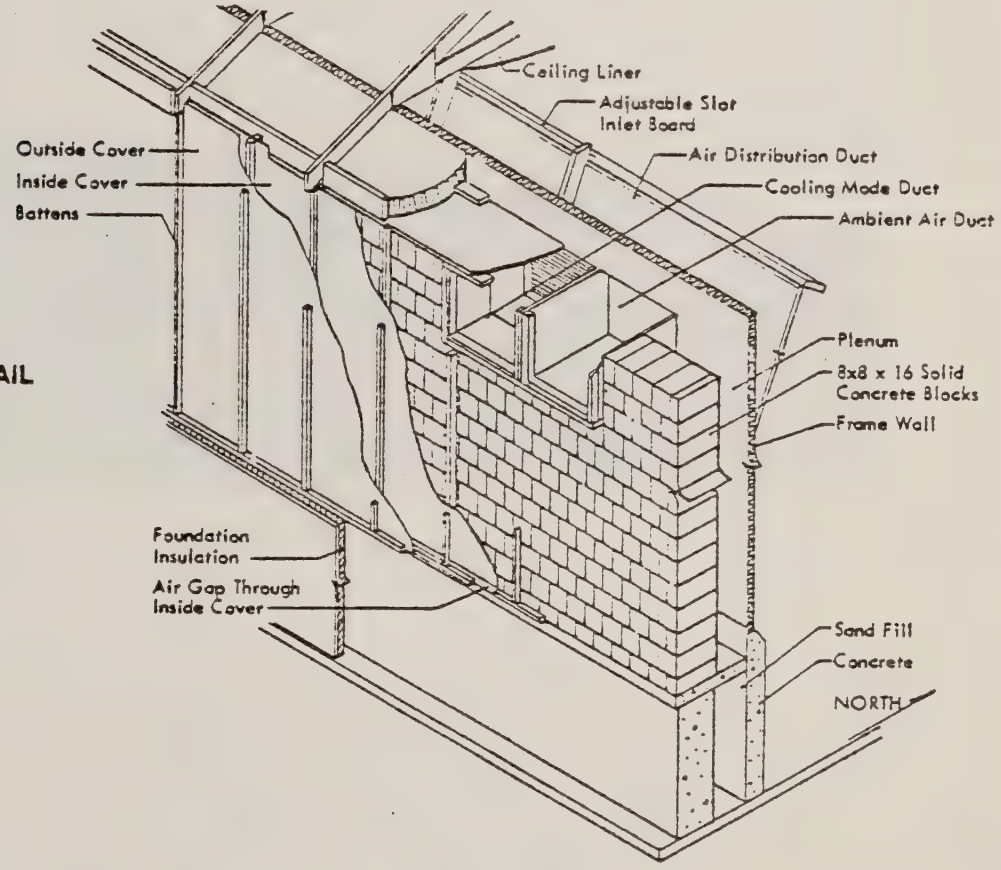


Mike Schwarz and Pat Murphy checking instrumentation in the Valley View Nursery. Air flow measuring device is shown immediately above instrumentation case.

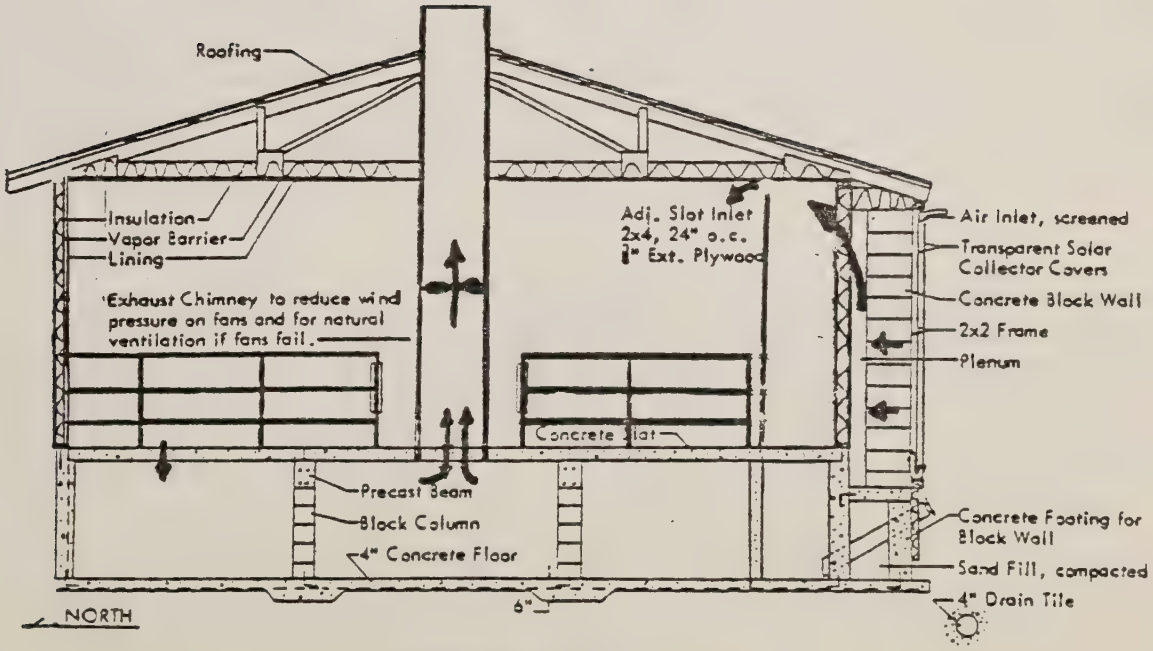


VALLEY VIEW FARMS, CLIFTON, KANSAS





SOLAR WALL DETAIL



CROSS SECTION

Visser Farms Demonstration

Visser Farms Demonstration
Riley, KS 66531



Building:

The building size is 28 ft. x 124 ft. and houses two 10 crate farrowing rooms, 2 weaning nursery rooms, and 2 grower nursery rooms. A small entry way and utility room separates the farrowing rooms from the nursery rooms. (Refer to plan view of building) Manure is removed from the building by flushing under slats. The main frame of the building is constructed with 2 x 6 stud walls with 6 inches of fiberglass insulation. Above the ceiling 10 inches of cellulose insulation was installed. The exterior shell of the building is covered with enameled metal and the interior walls of the ceiling are 1/2 inch exterior grade plywood. The floor of the building is partial slat floor. Supplemental heat is provided with non-vented propane furnaces. One 168,000 Btu/h furnaces serves both farrowing rooms and a 60,000 Btu/h unit is used in each nursery room.

Solar Collector:

On the south side of the building a solar wall was installed. This solar wall, developed at Kansas State University, consists of 2 fiberglass layers supported in front of a massive concrete block wall. Details for construction of the solar collector are given on page 5 of this report.

Ventilation of the rooms is accomplished with sidewall-mounted exhaust fans. The fans create a pressure reduction in the room which induces airflow through the solar collector. Outside air enters between the two transparent covers and then passes through the 3/16 inch vertical cracks in the concrete block wall. The solar-heated concrete tempers the ventilating air as it passes before entering the farrowing or nursery rooms.

Separate solar walls serve the farrowing rooms and nursery rooms. The solar wall for the two farrowing rooms measures 56 ft. by 7 ft., and the solar wall for the four nursery rooms is 61 ft. 8 inches by 7 ft. 8 inches. Airflow from the solar walls through the individual rooms is shown in Figure V3. During the heating season, the ventilating air from the two weaning nursery room is exhausted into the grower nursery rooms. This conserves valuable heat as the weaning rooms are kept much warmer than the grower rooms.

The total cost of the 392 sq. ft. solar wall for the farrowing rooms and the 472 sq. ft. solar wall for the nursery rooms was $6,900 or $7.99 per sq. ft.

Measured Performance:

The Visser solar-assisted swine building includes two farrowing rooms plus four nursery rooms. One KSU solar Wall supplies heat to the farrowing rooms, and another one supplies heat to the nursery rooms. We monitored the performance of the collector for the farrowing rooms only. Throughout the period when we monitored performance, the solar collector operated continuously to preheat the ventilating air for the farrowing rooms.

The only problem observed at this site was over-ventilation of both the farrowing rooms and the solar collector. The ventilation rate was often two to three times the recommended winter rate. This caused supplemental heat demand to be very high on a per farrowing stall basis. The flow rate through the solar wall was also about two to three times the recommended rate since all winter ventilating air enters the building through the solar collector. The high airflow rate caused high heat removal rates from the collector and resulted in wastage of significant solar energy during many afternoons.

The farrowing rooms have hot water pipes embedded in the concrete floor to provide additional warmth for the small pigs. The water temperature is maintained continuously at 105 F by an LPG fired water heater. We found that this warmed floor added a great deal of heat to the farrowing rooms, often more than the furnace. This heat input was continuous, and therefore on mild days the building often overheated, increasing the ventilating rate and wasting energy.

Table V1 is a summary of the measured performance of the farrowing portion of the building. In this table, only supplemental heat from the temperature-controlled furnace is included in heat demand since the heat from the warm floor was continuous and could not be reduced by solar energy. In this building, all supplemental heat is added to the ventilating air by the solar collector and then the LPG furnace. The temperature of the ventilating air was measured as it left the solar wall and as it left the furnace, so total supplemental heat and fossil-fuel heat were actually measured at this

building.

Table V1. Measured Performance of the Visser Solar-Assisted Farrowing Building

Time Period	Amb. Temp. °C	Solar[1] Temp. °C	Bldg.[2] Temp. °C	Flow[3] Rate kg/m²-h	Coll.[4] Energy mJ/m²	Heat Demand mJ/m²	Energy Saved mJ/m²	Fuel[5] Saved l/m²	Solar Frac. %
2/24-3/4	9.4	14.9	19.4	79.1	87	146	82	3.89	56
3/6-3/31	8.9	14.6	18.4	65.3	206	308	171	8.15	56
11/8-11/19	9.3	14.4	19.4	52.5	67	129	62	2.95	48
11/20-12/1	4.6	7.8	16.3	52.5	42	164	42	2.00	26
12/2-12/14	-3.2	6.6	15.7	42.6	116	228	114	5.45	50
Totals 66 days	6.1	12.0	17.8	58.8	518	975	471	22.49	48

1. Temperature of air leaving the solar collector-storage unit.
2. Ventilating air temperature after solar and furnace heating; farrowing room temperature was higher.
3. Airflow rate through solar collector-storage unit.
4. All energy quantities are stated per square meter of installed collector surface area.
5. Liquified Petroleum gas equivalent (backup fuel) calculated at 90% of the lower heating value (21 mJ/m³).

Projected Typical Annual Performance:

Using the measured performance results for the farrowing rooms, we developed an equation to predict supplemental heat demand as a function of the furnace setpoint temperature and the daily average outside air temperature. The prediction equation is:

$$\text{Suppl. Heat Demand} = 0.52\ (t_f - t_o) + 4.34 \quad \frac{\text{mJ}}{\text{m}^2\text{-day}} \qquad \text{Eq. V1}$$

Where: t_f = furnace setpoint, °C
t_o = outside air temp., °C

This equation is only approximate, since both the slope and intercept can vary with ventilating rate, animal size, and stocking density. Equation V1 will predict the typical monthly and annual heat demand of the farrowing rooms with reasonable accuracy by using long-term average ambient temperature data.

Using Equation V1 with long-term average ambient temperature data for Northcentral Kansas and simulated solar collector performance with Omaha, NE TMY data, we have projected typical monthly and annual performance of the farrowing rooms as described on page 3 of this report. The results are shown in Table V2. We used a furnace setpoint temperature of 25 C (77 F) and a collector airflow rate of 59 kg/m²-h (2.7 cfm/ft²). These values were obtained from our measured performance data.

Table V2. Typical Monthly Performance of the Visser Solar-Assisted Swine Building

Month	Collected[1] Solar mJ/m^2	Collection Efficiency %	Heat[2] Demand mJ/m^2	Energy Saved mJ/m^2	Fuel Saved l/m^2	Solar Fraction %
Jan.	281	68	580	250	11.9	43
Feb.	273	65	480	250	11.9	52
Mar.	239	60	466	215	10.2	46
Apr.	177	57	332	155	7.4	47
May	155	49	250	130	6.2	52
Sept.	205	58	205	130	6.2	63
Oct.	278	67	310	189	9.0	61
Nov.	242	68	435	208	9.9	48
Dec.	222	68	546	220	10.5	40
Annual	2072	63	3604	1750	83.2	49

1. Collected solar energy is from simulated performance of the KSU Solar Wall using Omaha, Nebraska TMY data and 28.8 kg/m^2-h collector airflow rate.
2. Supplemental heat demand calculated by Eq. V1 using Manhattan, Kansas temperature data. All energy quantities stated per square meter of solar collector

During a typical year, we project that the KSU Solar Wall on the Visser swine farrowing rooms would save 1750 mJ per square meter of collection surface (154,000 Btu/ft^2). For the 36.5 square meter (393 ft^2) collector, this is equivalent to 3030 liters (800 gal) of LPG. This is 49% of the energy required for temperature control. The heat demand in Table V2 excludes the heat supplied to the concrete floor.

This solar collector saves a large amount of fossil fuel because the building consumes a lot of energy and requires heat during nine months of the year. If the ventilation rate were reduced to the recommended value of 20 cfm per stall, energy demand could be greatly reduced. Fuel saved by the collector would also decline, but net fuel usage would be much lower.

The Visser building also includes a 44 square meter (473 ft^2) KSU Solar Wall which supplies heat to four swine nursery rooms. This collector and the four rooms were not monitored; however, based on our experience with the Keesecker and Benteman nurseries and the farrowing rooms just discussed, we have estimated the typical performance of this collector. The heating season for swine nurseries is normally shorter than for farrowing houses because of the higher animal density and greater internally generated heat; as illustrated by the Keesecker and Benteman nurseries (Tables K2 and B2). We estimate that the nursery rooms typically require negligible heat during May and September so no fuel is saved by the collector. During the remainder of the year, we believe the collector for the nurseries performs much like the farrowing room collector. Therefore, we project annual fuel savings from the collector supplying the nurseries is 1490 mJ/m^2 (131,000 Btu/ft^2). We also project that the collector supplies 35% of the heated required by the four nursery rooms.

Economic Feasibility Analysis:

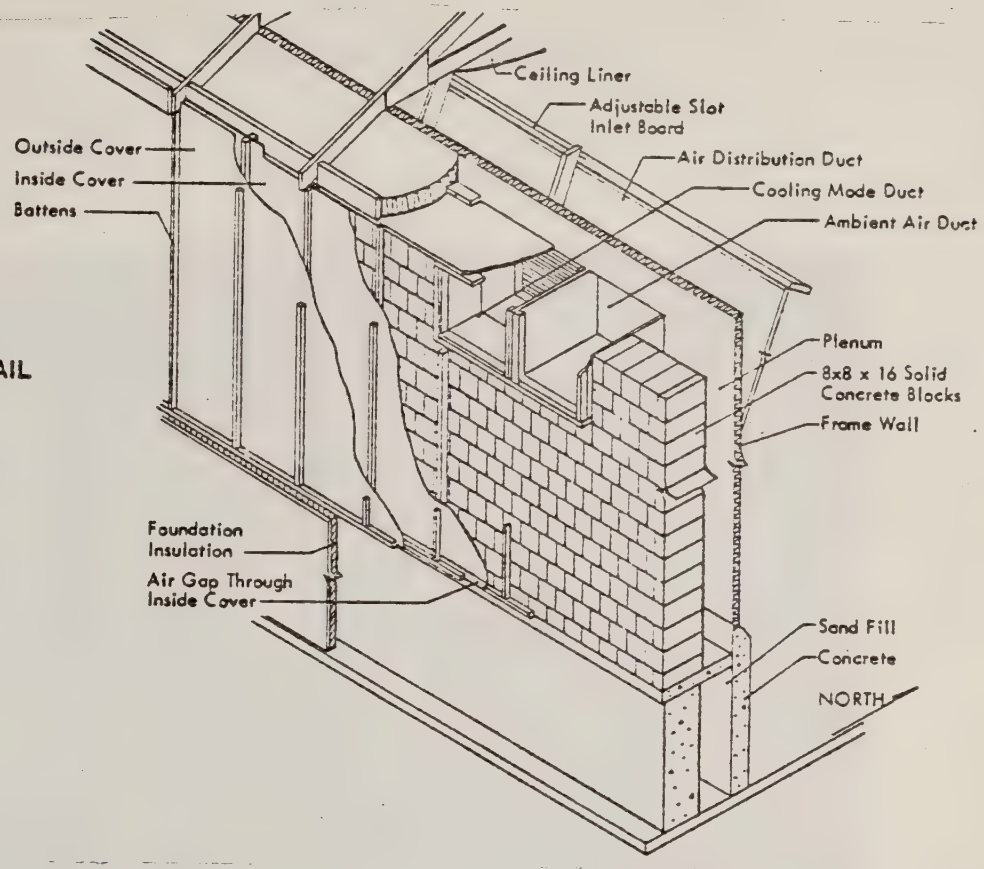
The Visser swine confinement building is heated by two KSU Solar Walls and non-vented space heaters fueled by LPG. Assuming the space heaters are 90% efficient, the typical annual fuel saved by the two collectors (average for both) is 76.5 liters of LPG per square meter (1.88 gal/ft^2). The two solar collectors had a total installed cost of $6,900 or $85.70 per square meter ($7.99/ft^2). With this cost and fuel savings rate, and the economic parameters in the following list, a life-cycle economic analysis shows that these two solar collectors will pay for themselves in ten years and provide a 19% inflation-adjusted, after-tax annual return on the invested capital.

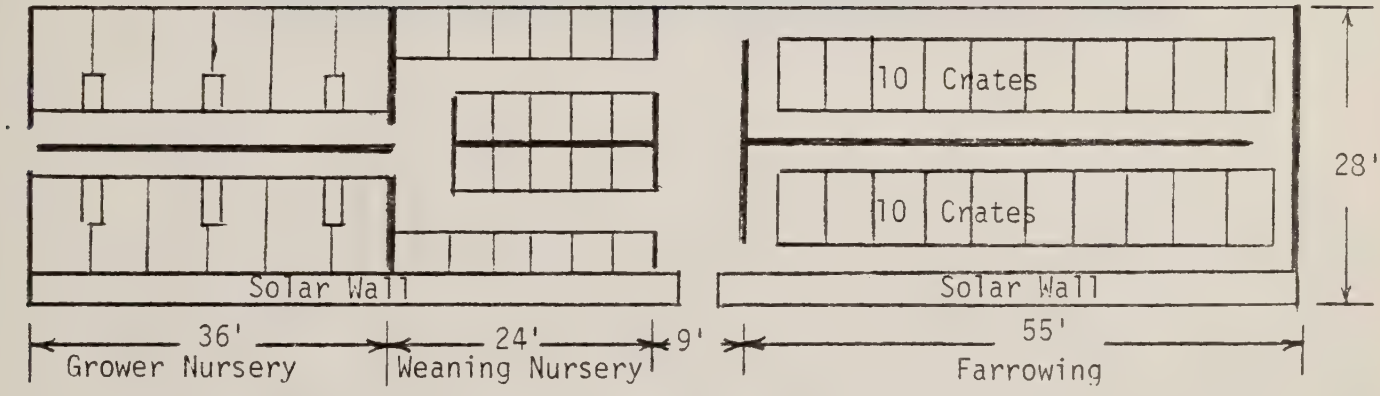
Economic Parameters in Analysis

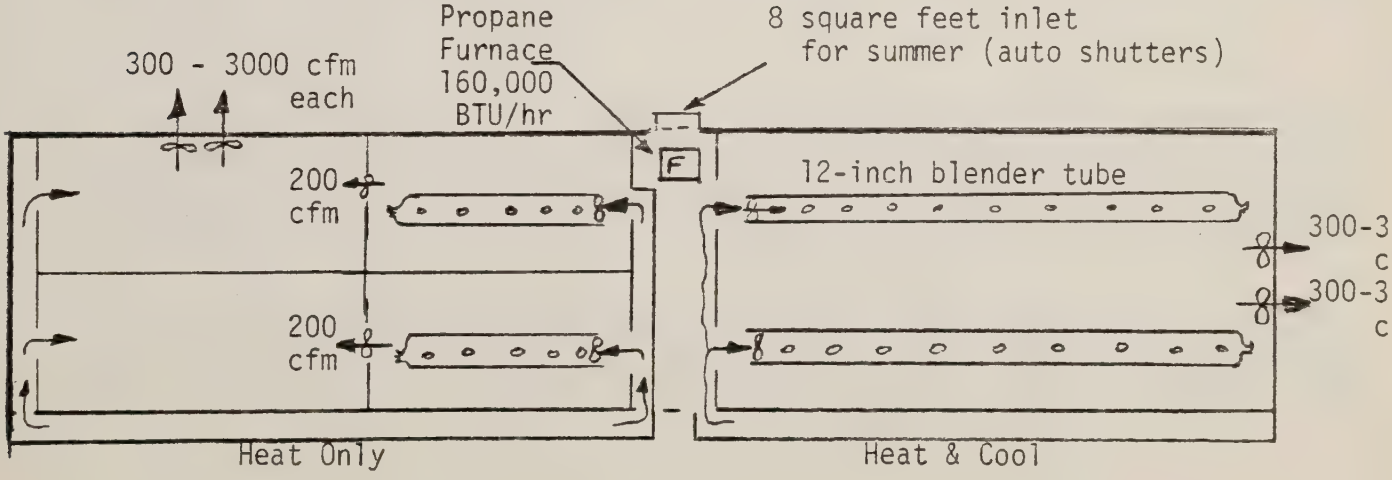
55% tax credit (25% Federal + 30% State)
$20 per square meter salvage value
10 year economic life
$0.15/liters LPG initial fuel cost
10% fuel price inflation
7% general inflation
25% tax bracket

This is a very good return on the invested capital. It is high enough that these two collectors would have been economical even without solar tax credits. The solar collectors could have been increased significantly in size to take better advantage of the tax credits and also make better use of available capital. However, the very high performance of these collectors is due largely to the high energy use of the building. If measures are taken to better control ventilation rate and reduce energy demand, collector performance will decrease some and building operating costs will decrease greatly.

SOLAR WALL DETAIL



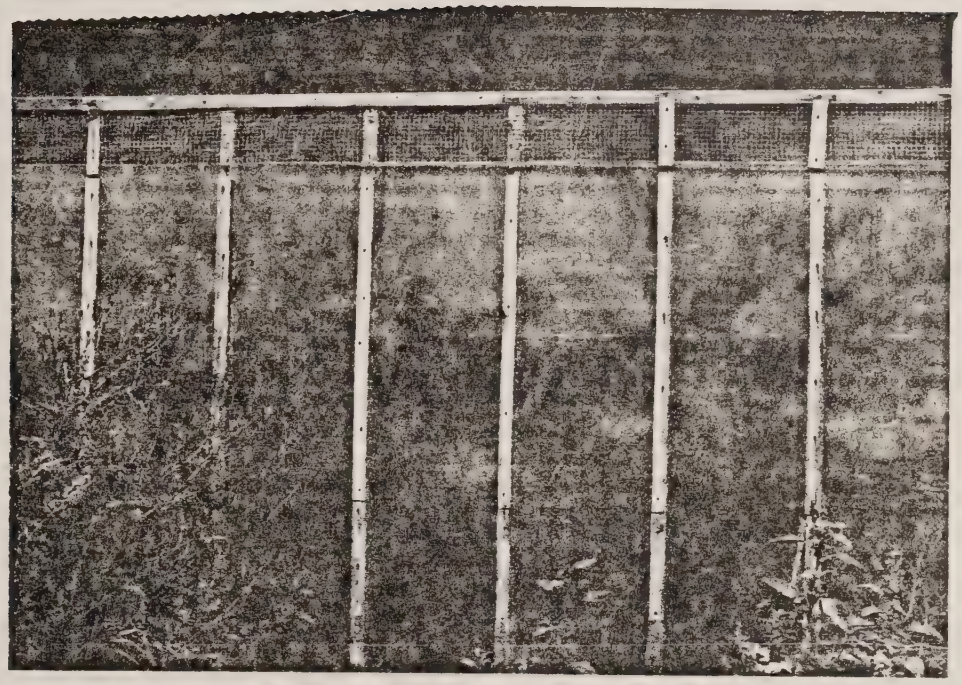




Note: Solar wall design in MWPS 81902 with flush gutter option,

Robert Wedel Demonstration

Robert Wedel
Greensburg, KS 67054



Building:

The building is 24 ft. wide including solar collector by 36 ft. long. It includes a 28 ft. long farrowing room with 10 farrowing crates and an 8 ft. long utility room on the east end. The main frame of the building is constructed with 2 x 6 stud walls with 6 inches of fiberglass insulation. Above the ceiling 10 inches of cellulose insulation was installed. The exterior shell of the building is enameled metal and the interior walls and ceiling are 1/2 inch exterior grade plywood. The floor of the building is partial slat floor with in-house manure storage. Supplemental heat is provided by a 60,000 BTU/hr non-vented propane furnace.

Solar Collector:

The solar collector is 7 ft. - 10 inches high by 28 ft. long vertical wall on the south side of the building. This solar wall, developed at Kansas State University, consists of 2 fiberglass layers supported in front of a massive concrete block wall. Details for construction of the solar collector are given on page 5 of this report.

Two 18 inch fans which are installed in the north sidewall of the building regulate the airflow through the building. These fans cause a vaccum which induces air to flow between the fiberglass covers, and then through the

3/16 inch vertical cracks in the block wall. The blocks then temper the air before it enters the farrowing room. Air flows from the blocks into the room. Air is then exhausted through a side wall fan on the north wall.

Total installed cost for the 218 sq. ft. collector was $2,437.20 or $11.18 per sq. ft.

Measured Performance:

The performance data collected at the Wedel swine farrowing building indicated that the building and solar collector operated quite well. Performance results for four periods, 50 days total, in 1981 are presented in Table W1. During the 50 day period, the building was maintained at approximately 25 C (77 F) while furnace setpoint was approximately 22 C (72 F). Both the building and the solar wall were ventilated at the rates we recommended. This resulted in very reasonable heat demand and good solar collector performance. For the overall data period, 69% of the collected solar energy saved fossil fuel and the savings was 87% of total demand. This farrowing house was operated the most efficiently, from an energy standpoint, of all the seven buildings with KSU Solar Wall collectors.

Table W1. Measured Performance of the Wedel Solar-Assisted Swine Farrowing Building

Time Period	Amb. Temp. °C	Solar[1] Temp. °C	Bldg. Temp. °C	Flow[2] Rate kg/m²-h	Coll.[3] Energy mJ/m²	Heat Demand mJ/m²	Energy Saved mJ/m²	Fuel[4] Saved l/m²	Solar Frac. %
1/4-1/14	0.7	16.2	23.0	19.8	79	78	67	3.20	87
1/15-1/24	2.0	16.4	24.4	19.7	62	53	42	2.02	80
2/14-2/28	10.2	22.0	25.8	29.2	118	102	88	4.17	86
3/25-4/10	12.0	21.0	25.9	29.0	97	49	47	2.26	97
Totals 50 days	7.2	19.4	25.0	25.4	356	282	245	11.65	87

1. Temperature of air leaving the solar collector-storage unit.
2. Airflow rate through solar collector-storage unit.
3. All energy quantities are stated per square meter of installed collector surface area.
4. Liquid petroleum gas equivalent (backup fuel) calculated at 90% of lower heating value (21 mJ per liter).

Projected Typical Annual Performance:

The Wedel demonstration site is located only 40 miles from Dodge City, Kansas, a Class A weather station for which hourly 'typical meteorological year' (TMY) data are available. This building was operated nearly identically to a farrowing house, with KSU Solar Wall, whose performance had been simulated hourly by using the computer simulation discussed on page 3 with Dodge City TMY data. Therefore, for this building, we took the projected typical annual performance directly from the hourly computer simulation. The projected monthly performance of this building is presented in Table W2.

Table W2. Typical Monthly Performance of the Wedel Solar-Assisted Swine Farrowing Building

Month	Collected[1] Solar mJ/m^2	Collection Efficiency %	Heat Demand mJ/m^2	Energy Saved mJ/m^2	Fuel Saved l/m^2	Solar Fraction %
Jan.	219	47	336	219	10.4	65
Feb.	197	43	273	200	9.5	73
March	189	42	213	160	7.6	75
April	135	38	132	102	4.9	78
May	106	35	48	44	2.1	94
Sept.	201	48	25	25	1.2	100
Oct.	261	52	173	150	7.1	87
Nov.	203	48	237	182	8.7	77
Dec.	181	46	301	190	9.0	63
Annual	1690	45	1740	1270	60.5	73

1. Performance from hourly simulation using Dodge City, Kansas TMY data with 21 kg/m^2-h collector airflow rate.

The solar wall provides a large portion of the supplemental heat for this farrowing house throughout the year. The projected solar fractions are somewhat lower than we measured; however, outside temperatures were significantly higher than the long-term norms during the measured periods. In a typical year, this collector should save the equivalent of 1225 liters (324 gal) of LP gas (calculated at 90% of lower heating value) which is 73% of the building's total heat demand.

Economic Feasibility Analysis:

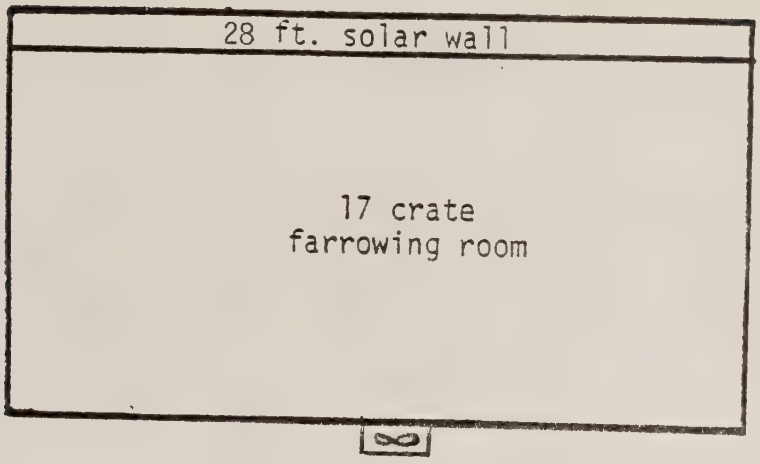
The Wedel farrowing house is heated by the KSU Solar Wall and a non-vented space heater fueled by LP gas. Assuming the space heater utilizes 90% of the lower heating value of the fuel, the energy saved annually by the solar wall is equivalent to 60.5 liters of LPG per square meter of collector (1.49 gal/ft^2). The installed cost of this solar wall was $120 per square meter of collection surface ($11.18/$ft^2$). Using this collector cost and annual fuel savings we performed a life-cycle economic analysis on this collector using economic parameters in the following list. The analysis reveals that this solar collector will pay for itself in ten years with a 6% inflation-adjusted, after-tax, annual return on the invested capital.

Economic Parameters in Analysis

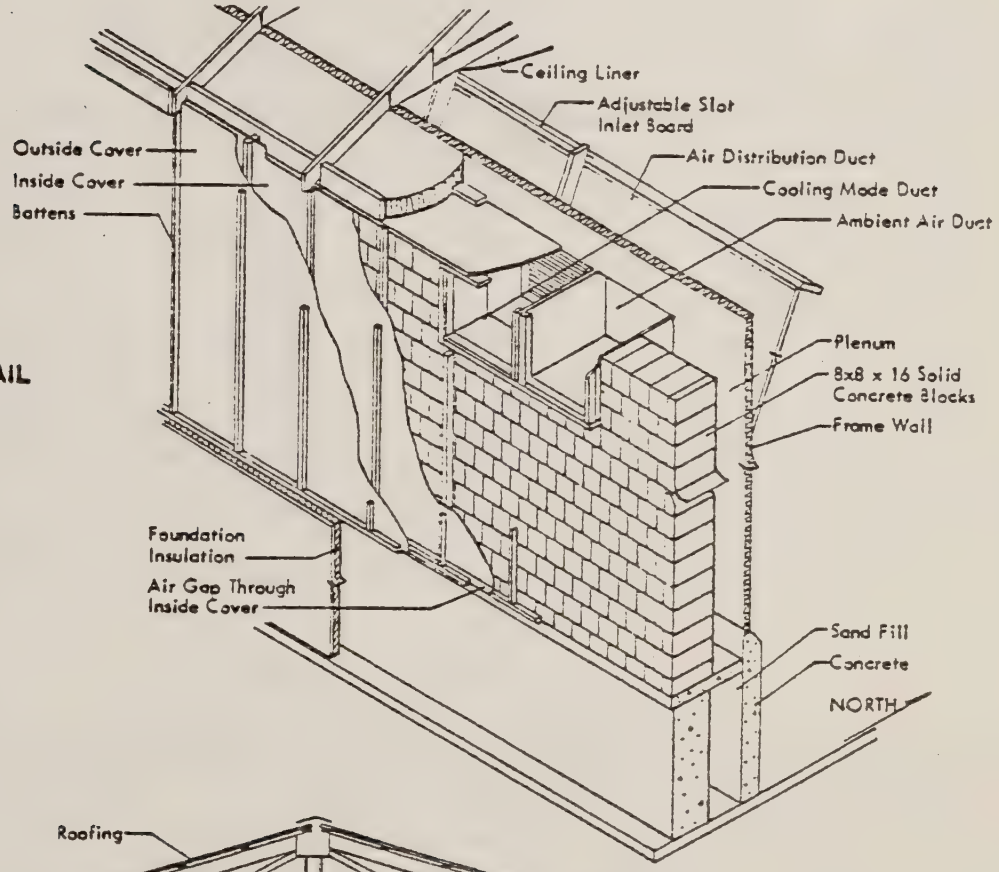
55% tax credit (25% Federal + 30% State)
$20 per square meter salvage value
10 year economic life
$0.15/liters LPG initial fuel cost
10% fuel price inflation
7% general inflation
25% tax bracket

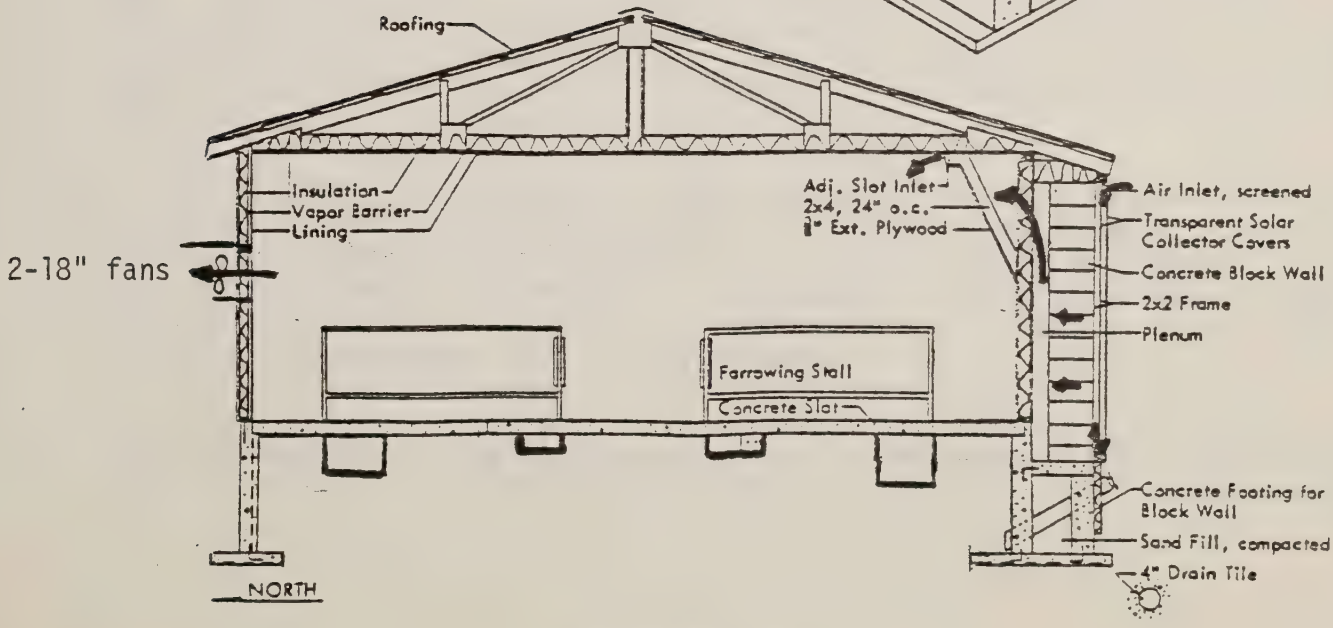
This solar collector was sized properly for the farrowing house it serves. It provides an adequate economic return and also provides a high percentage of the building's annual heating requirement. The building was well-operated such that the heating demand was not extremely large. This collector provided nearly optimal use of the owner's capital.

ROBERT WEDEL, GREENSBURG, KANSAS



SOLAR WALL DETAIL





CROSS SECTION

Summary

The following table gives the performance summary of the nine demostration projects. The first column gives the initial cost of the collector on a square foot basis. The second column indicates the fuel savings per heating season in equivalent gallons of propane per square foot of collector area that could be projected for the units over a heating season. The third column indicates the percentage of the building's heat supplied by solar energy. The last column gives the inflation-adjusted, after-tax annual return that the collectors supplemental provides.

	Collector Initial Cost $/ft^2$	Annual Energy Saved gal LPG/sq. ft.	Annual Solar Fraction %	Annual Economic Return %
Goertzen Farm	6.78	1.51	53	16
Hobson Farm	6.20	0.23	93	1
Hund Farm	5.43	1.84	38	26
Keesecker Farm	8.07	1.06	30	6
Pifer Farm	8.38	1.36	58	1
Premium Pork Farm	12.00	1.40 a.	b.	b.
Valley View Farm	12.71	1.94	25	9
Visser Farm	7.99	1.88	41	19
Wedel Farm	11.18	1.49	73	6

a. Estimated achievable performance. It was not achieved due to equipment malfunction.
b. Value could not be calculated due to malfunction of equipment.

Educational Activities

The Agricultural Engineering Department manned an outdoor lot at the Kansas State Fair in Hutchinson, Kansas, on September 6 through September 16, 1980. One-third of the lot space was devoted to solar energy education. A scale model of the solar unit developed at Kansas State University was displayed along with materials that explained the operation of the solar heater. The initial goals and locations of the on-farm demonstrations of solar heating of livestock structures were reported.

During our 1980-81 extension year, county and area meetings were utilized to explain the solar livestock demonstration grant to the general public. The following counties hosted these meetings: Doniphan, Cheyenne, Seward, Scott, Ellis, Dickinson, Pottawatomie, Wabaunsee, Washington, Osage, Wilson Montgomery, Bourbon, Linn, Neosho, Jefferson, Brown, Republic, Haskell, Gray, Finney, Stanton, Marion, Harvey, and McPherson.

On November 13, 1981, mass media was utilized through two television stations to explain the solar livestock demonstration grant. The Kansas State radio network was utilized in conjunction with an energy fair on July 25 and

16, 1981 for in-depth interviews to also explain the purposes of the demonstration grant. On November 8, at the Kansas State University Swine Day, a tour was held at the farrowing house solar heater site to explain its function.

Additional exposure was given to the solar livestock heating demonstration grant through University seminars and professional society engineering meetings. The July, 1980, Science and Education Administration Newsmakers newspaper carried a special feature about the solar heaters. The newspaper featured Arlen Benteman and his solar demonstration project. Our Kansas farm magazines and newspapers have carried many stories about the solar livestock demonstration.

During December of 1980, Dale Keesecker from Washington, Kansas, one of our solar demonstrators, traveled to Washington, D.C., to receive a national energy conservation award from President Carter. Many press releases resulting from that visit have appeared in all the local papers.

On February 10, 1982, an update on the results of the solar demonstrations was given to the Kansas Pork Producers Council meeting at Wichita, Kansas. At the Mid Central American Society of Agricultural Engineer's meeting, a paper was given entitled "A Data Logging System Using A SYM-1 Microcomputer" which described the data collection system used on the solar demonstration.

In our 1981-82 extension year, county and area meetings were utilized to inform livestock producers about the solar demonstration. Meetings were held in the following counties; Nemaha, Butler, Ford, WaKeeney, Saline, Phillip, Republic, Anderson, Bourbon, Labette, Harvey, Pottawatomie, Seward, Grant, Reno and Marshall. Interest in the solar demonstration remained high but low livestock prices did not encourage the construction of new units. The solar demonstration cooperators gave "first hand" information about their solar buildings at many county livestock meetings across Kansas.

UNIVERSITY OF MINNESOTA
TWIN CITIES

Department of Agricultural Engineering
Agricultural Engineering Building
1390 Eckles Avenue
St. Paul, Minnesota 55108

DATE: September 22, 1982

TO: Dr. E. C. Pilgram, Project Leader
Solar Energy Livestock Ventilation Demonstration

FROM: Dr. K. A. Jordan, Project Manager

SUBJECT: Summary and Final Report of Demonstration Project

Minnesota's involvement in the National "Solar Energy Livestock Ventilation Demonstration Project" has been providing useful information for the proper application of solar energy in livestock ventilation systems in the state. A wide range of system types and construction methods were involved: commercially fabricated and installed units; proven systems (with local modifications good and bad) built either by a contractor or the farmer himself; and systems already built of unproven design.

Our prior involvement in the Solar Assisted Livestock Ventilation Research Project provided a great deal of valuable experience which was applied to this demonstration project. Discussions with farmers on system design ranged from rather brief discussion for the commercial units to several lengthy sessions with extensive calculations required for some of the modified units. As with other plans farmers exhibit extensive innovative ability. Some of these ideas were well founded; others were not. Those we felt were not well founded we discussed with the farmers, but some farmers were not convinced and implemented them against our recommendations. We felt this was the realistic role which we will be asked to play beyond the demonstration period. We went ahead with the modifications the farmer wished to make unless they were contrary to good engineering practice. (One potential cooperator was not included because a suitable design could not be agreed upon.)

The most significant problem encountered was the more stringent construction practices needed to eliminate air leaks. The second was establishing the animal ventilation needs and sizing the solar energy collection system to this air flow rate.

Careful planning, construction, management, and maintenance can make solar heating of livestock housing a significant economic alternative to coventional heating. The collection system must be thoroughly planned so that it does not interfere with existing structures and has complete access to solar radiation all day without obstruction from other buildings. The collector must be sized for the building and purpose the energy is intended for so that the system's output will be great enough to be useful, and yet not so large or expensive that the energy cannot pay for the system that is installed in a reasonable length of time. All of these things need to be worked out before any solar energy collection system is purchased or constructed.

Next, paying close attention to detail during construction can make the difference between a low maintenance efficient solar system and a poor economic investment. All joints and seams in the collection system should be well fitted and sealed with a durable sealant to prevent air infiltration into the system from any source other than the intended inlet. The inlet is designed for even distribution of air across the collector, and leaks defeat its purpose. The use of a good quality sealant is also important as it will reduce time spent on maintenance.

The conclusions drawn from this project would be:

1) The design of a solar energy collection system for livestock ventilation is complex enough to require design help from people familar with both solar energy systems as well as animal ventilation systems.

2) For a properly designed system the farmer should minimize the cost of the installed system per square foot of collector surface.

3) Sealing of air leakage in the system is grossly overlooked but absolutely essential to efficient collection of usable heat from solar sources.

Attached are descriptions of the demonstration units with the results of our measurements.

KAJ:lmk

Enclosures

To: Kenneth Felton, Agricultural Engineer
On-Farm Demonstrations of Solar Heating
of Livestock Shelters

From: Kenneth Jordan, Project Leader
Minnesota Demonstrations

Subj: Addendum to Final Report
Utilization Plan

The results of the demonstration have been distributed to the county agents for informational purposes. This will be followed up with several Fact Sheets which are in preparation. A audio-slide presentation has been given in two locations in the state which will be improved and copies made for general agent and media use.

Energy meetings where solar options are discussed indicating where the economics are favorable and what criteria the farmers should use have been held at the following locations by Larry Jacobson, extension specialist:

Dec 14, 1981	Granite Falls/Clara City
Jan 4, 1982	Verdi Crop Show
Jan 22, 1982	MN Pork Producers Meeting
Feb 17-18, 1982	Swift and Stevens Co.
Mar 5, 1982	Pork Clinic; New Richland

Meeting planned by Larry Jacobson where the place of solar energy in supplimenting the energy needs of livestock ventilation systems will be discussed:

Dec 16, 1982	Swine Herd Health Clinic, St. Cloud,MN
Feb 21-22, 1983	Health Clinics, S.W. MN
Feb 24, 1983	Swine Forum, Braham
Feb 28, 1983	Swine Forum, Dakota Co.
Mar 3, 1983	McLeod Co Meeting
Mar 16, 1983	Livestock meeting, Walker

Numerous phone calls have been taken from the general public indicating a mild interest in using solar energy in livestock ventilation systems. Five calls have been taken where detailed information was requested for solar energy applications. One county agent requested an evaluation of a plan being distributed by a lumber company for a solar collector made of materials supplied by the company.

A number of journalists have phoned (ten or so) and three asked for personal interview for stories that they were writing for the rural audience. Copies were usually requested of the article but only one journalist complied.

Journal articles in Transactions of the ASAE are contemplated but a definite time table has not been set.

A 90 PIG NURSERY in Blue Earth County Minnesota with valid collection data since January, 1981 featuring:

208 sq. ft. of double glazed Thrombe wall.

520 cu. ft. of concrete block storage, (silo staves laying flatwise).

700 sq. ft. of swine nursery to space heat with an A.U. value of 119 Btu/hr.-degree F.



SYSTEM DISCRIPTION: Solar energy is used for space heating in this 90 pig nursery. The collecter is a south facing twenty-six by eight foot wall of concrete silo staves with a double glazing of ribbed fiberglass reinforced Filon. This vertical collector pulls intake air from the attic area down between the two sheets of Filon and then between the blocks to three adjustable openings built into the south interior wall of the nursery. Air flows through the collector to the nursery as a result of the exhaust ventilation fans in the east wall. Additional heating requirements are fulfilled by a forty thousand Btu/hr propane gas heater mounted from the ceiling on the west end of the room.

COST: Total cost of the solar collection system was $7,000, or $33.65 per square foot of collector area.

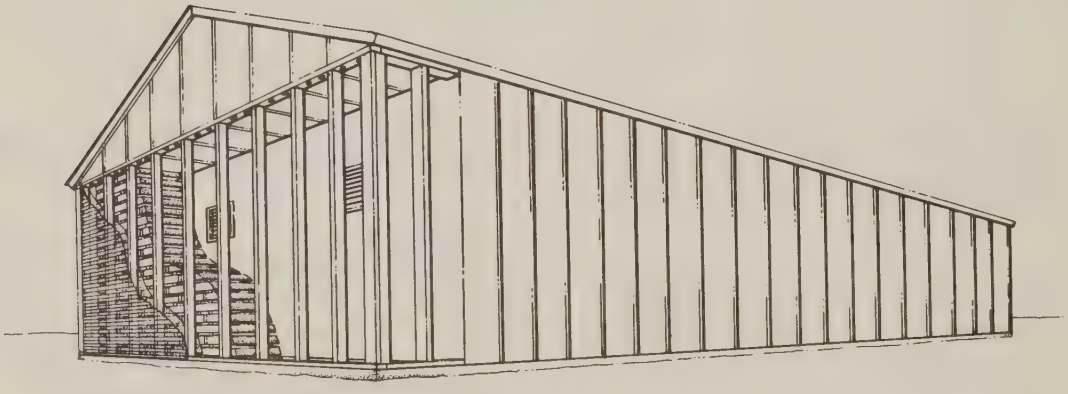
PERFORMANCE SUMMARY: The solar collection system at this farm provided 21% of the energy needed to heat the nursery during the September, 1981 through April, 1982 heating season. The collector system captured a nominal 25% of the solar radiation that fell on it and saved approximately $158 in propane, (at $0.65 per gallon), that would otherwise have had to been purchased.

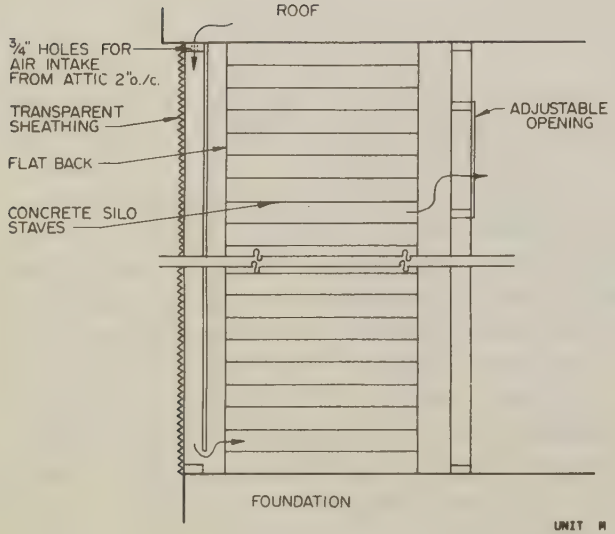
COMMENTARY: This solar installation is a good example of the use of available materials in a planned new construction. Solid concrete blocks, used in Thrombe wall collector systems, can be hard to find and expensive. These silo stave seconds performed very well and at a fraction of the cost of new solid blocks. However this installation was not problem free.

In an effort to increase summer ventilation requirements, a large vent was initially built in the front of the collector so that outside air could bypass the collection system and flow directly to the outlet ducts in the nursery. While this duct remained as part of the installation it was never air tight, leading to reduced flow through the blocks which resulted in inefficient operation due to heat loss through the collector. It also resulted in the entrance of cold untempered air into the the nursery during days that the winds were from the south. Performance could have been noticably increased had this duct been removed earlier in the season.

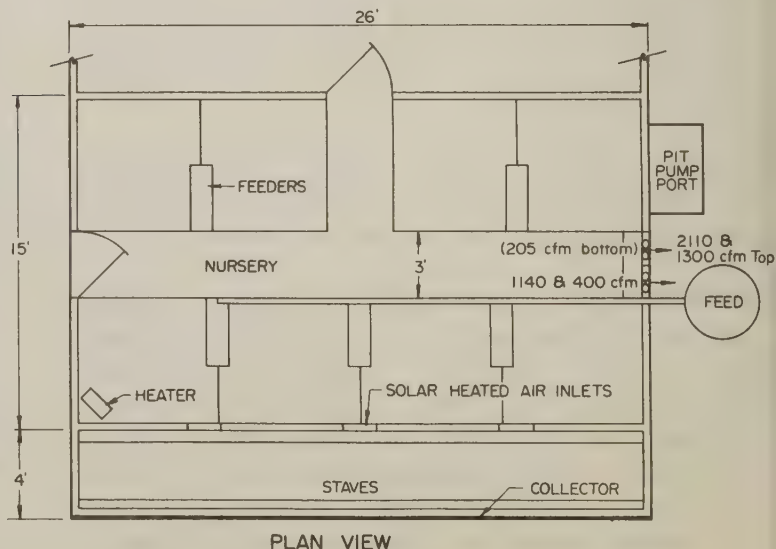
SYSTEM PERFORMANCE FROM SEPT '81 TO APR '82

MONTH	AVE. OUTSIDE AIR TEMP. C	HEAT PURCHASED	HEAT COLLECTED	ANIMAL HEAT
		(Millon British thermal units)		
Sept	13.1	-0-	2.00	5.33
Oct	6.5	2.29	1.98	5.41
Nov	1.7	3.95	2.47	3.66
Dec	-10.2	6.83	2.45	2.00
Jan	-10.1	20.39	3.84	4.30
Feb	-12.3	7.47	4.14	1.36
Mar	- 2.2	8.00	3.33	4.15
Apr	9.3	3.89	2.18	4.33
TOTAL	----	52.82	22.39	30.54





UNIT A



PLAN VIEW

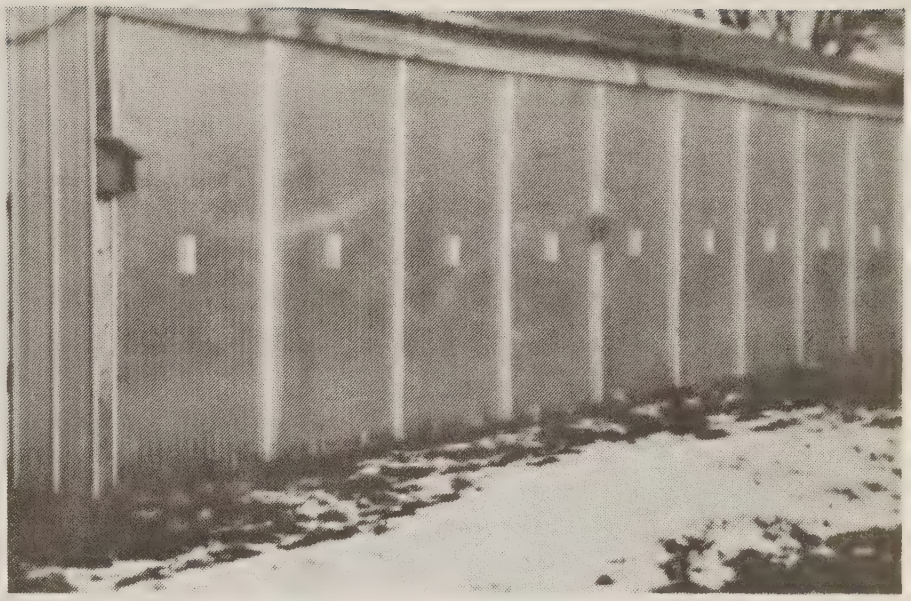
UNIT A

A 85 SOW GESTATION BARN in Renville County Minnesota operating since January 1981 with:

320 sq. ft. of double glazed Thrombe wall.

391 cu. ft. of solid concrete block storage.

2304 sq. ft. of swine gestation barn to space heat wihtout back-up heat.



SYSTEM DESCRIPTION: Solar energy provide all of the supplementary space heating in this 85 sow gestation barn. The vertical wall collector is forty feet long by eight feet high and is centered on the south wall. It features a double glazing of Filon ,(fiberglass), mounted several inches in front of an eight by forty foot wall of concrete blocks that are used for solar energy storage. The blocks are stacked with a 3/8 inch spacing between each other to allow air to pass through the wall. Several inches behind the blocks is the original south wall of the building. The space between the blocks and the building acts as a plenum from which a 735 c.f.m. fan draws the solar heated air through an opening and exhausts it into the building.

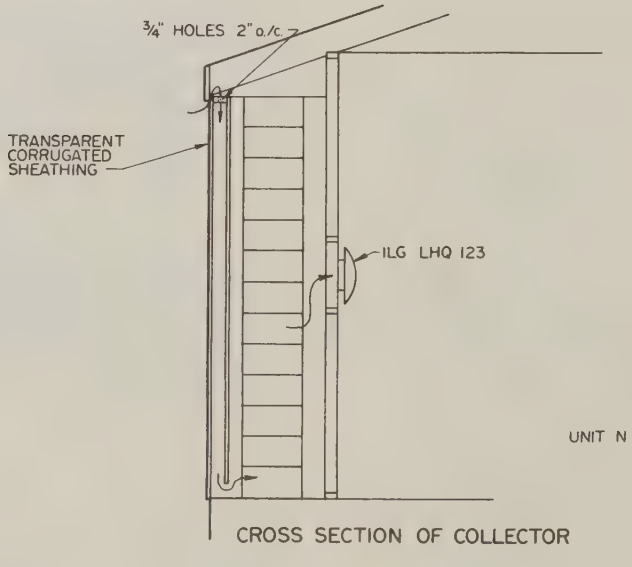
COST: The cost of adding the solar collector and storage system to this building was $4125.92, or $13.88 per square foot.

PERFORMANCE SUMMARY: The solar collection system at this farm provided 100% of the energy needed for space heating and maintained the building temperature at an average of 15.4 degrees Celsius for the September 1981 to May 1982 heating season. The collector system captured a nominal 40% of the incident solar radiation that fell on it and saved approximately $750 in electrical energy, (at $0.05 per kilowatt-hour), or $520 in propane, (at $0.65 per gallon), that would otherwise have been needed to maintain a satisfactory temperature within this gestation barn.

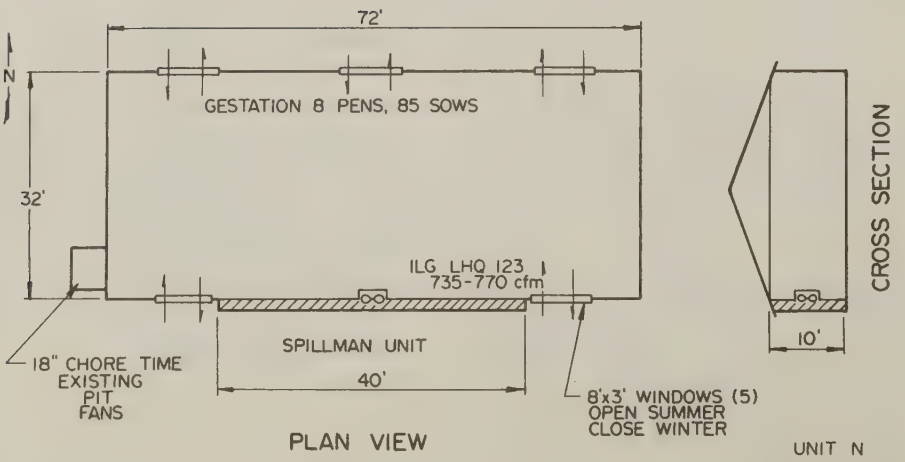
COMMENTARY: This collection system has been relatively problem free with the exception of minor leaks around the fan unit which allowed room air to recycle into the solar plenum behind the fan. Careful construction and the close attention spent on sealing this unit made for nearly maintenance free, and very efficient, operation. The solid block storage wall, with the 735 c.f.m. fan, produced a 12 hour lag between the time that solar incident radiation peaked and the largest temperature difference between outside and inside air occurred.

SYSTEM PERFORMANCE FROM SEPT '81 TO MAY '82

MONTH	SOLAR HEAT COLLECTED (Kilowatt-hr.)	TEMP. OUTSIDE	TEMP. FROM COLLECTOR (degree celsius)	TEMP. INSIDE	COLLECTOR EFFICIENCY
SEPT	1810.24	11.2	17.1	17.1	54.3
OCT	1946.15	5.6	11.7	14.1	43.9
NOV	1489.26	2.0	6.8	15.0	28.8
DEC	1689.03	- 6.0	- 0.7	14.2	42.1
JAN	2195.85	-17.8	-10.8	10.8	45.8
FEB	1863.44	-9.6	- 3.1	13.2	40.1
MAR	1626.30	- 2.1	3.0	16.7	47.7
APR	1137.30	9.5	13.2	17.9	30.2
MAY	1216.86	13.1	16.9	17.8	43.9
AVERAGE	1663.88	0.7	6.0	15.4	41.2%



CROSS SECTION OF COLLECTOR



PLAN VIEW

A 24 SOW FARROWING BARN in Big Stone County Minnesota operating since January, 1981 with:

Two 208 sq. ft. Thrombe wall solar collection units.

548 cu. ft. of solid concrete block storage.

1,920 sq. ft. of swine farrowing house to supplement space heat with an A.U. value of 641 Btu/hr.-degree F.



SYSTEM DESCRIPTION: Space heating in this farrowing house is accomplished with the combination of a 40,000 B.t.u. per hour water heater which heats the floor of the building, a 60,000 B.t.u. per hour liquid propane space heater, and two 29.25 by 7.1 foot solar collection systems. The solar collectors are built on the south side of the building under an extension of the roof. This collector features a double glazing of Filon fiberglass with air intake located at the top of and between the two glazings. Inlet air is drawn from the top of the collector down between the sheets of fiberglass and heated by solar radiation. Between the glazing and the south wall of the farrowing barn is a wall of concrete blocks stacked with a 1/4 inch space between each other. The space between the block walls and the south wall of the building is used as a hot air plenum for the solar collection system. Two 218 c.f.m. fans, one in each collector, are mounted in the south wall of the building and draw air through the solar collection and block storage system and exhaust it into the farrowing rooms.

COST: The total cost of adding the solar collection and storage system to the building was $8,905.00 or $21.44 per sqare foot of collector.

PERFORMANCE SUMMARY: The solar collection systems at this farm provided a nominal 12% of the energy needed for space heating in the farrowing house during the November, 1981 through March, 1982 heating season. The collection system captured about 24% of the incident solar radiation that fell on it, resulting in an approximate savings of $160 of propane, (at $0.65/gallon), or $230 if electric resistance heat had been used, (at $0.05/kilowat-hour).

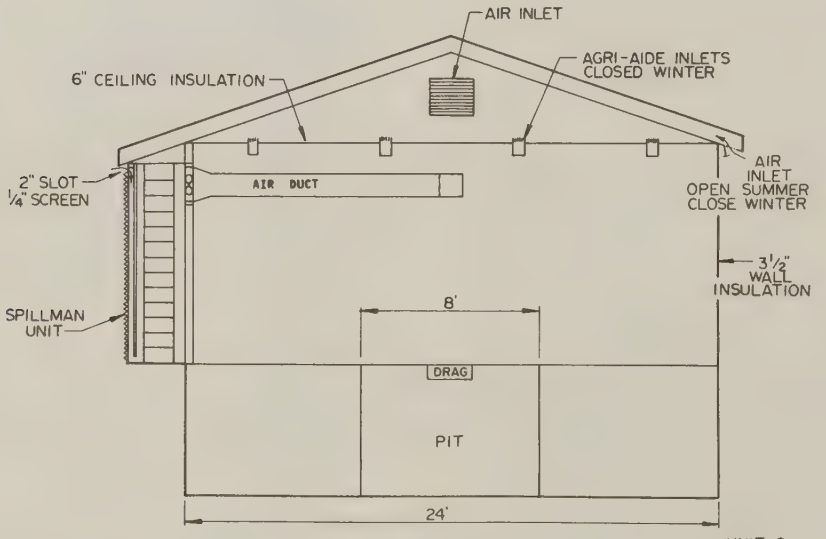
COMMENTARY: The solar collection system on this farm had two major problems; numerous air leaks and a feed storage bin existing in front of one collector.

Air leaks are the most common and troublesome problem in most solar collection systems. The infiltration of cold outside air into the collection systems hot air plenum reduces air flow through the concrete block storage and introduces cooler air into the heated space that would otherwise have been realized. Collectors should be inspected and sealed at least annually.

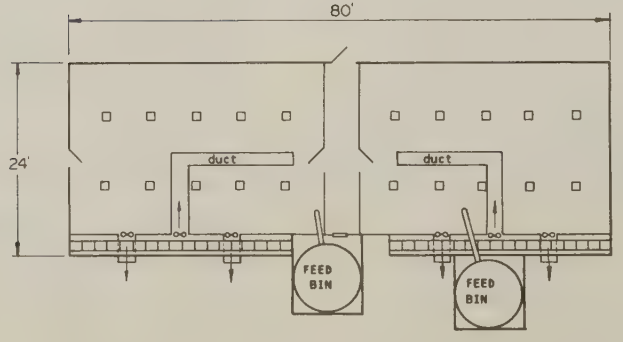
The second problem is obvious. The grain storage bin built in front of one of the collectors shields the collection system from a great deal of the direct solar radiation that would otherwise fall on the collector, it was intended that this problem would be overcome by moving the bin.

SYSTEM PERFORMANCE FROM NOV '81 TO MAR '82

MONTH	SOLAR HEAT COLLECTED (Kilowatt-hours)	PROPANE PURCHASED (Kilowatt-hours)	TEMPERATURES OUTSIDE (degrees celsius)	TEMPERATURES OUT COLLECTOR (degrees celsius)	TEMPERATURES INSIDE (degrees celsius)	EFFICIENCY
NOV	998.85	3693.69	- 3.8	1.7	18.7	60.6
DEC	1093.56	8206.45	-12.8	-3.7	21.6	28.6
JAN	1134.29	10290.40	-18.4	-6.4	19.0	24.2
FEB	813.05	6526.99	- 7.6	1.9	22.2	15.7
MAR	661.23	6400.23	- 2.0	3.2	21.6	15.1
AVERAGE	930.20	7023.55	- 8.9	-0.7	20.6	23.8%



CROSS SECTION



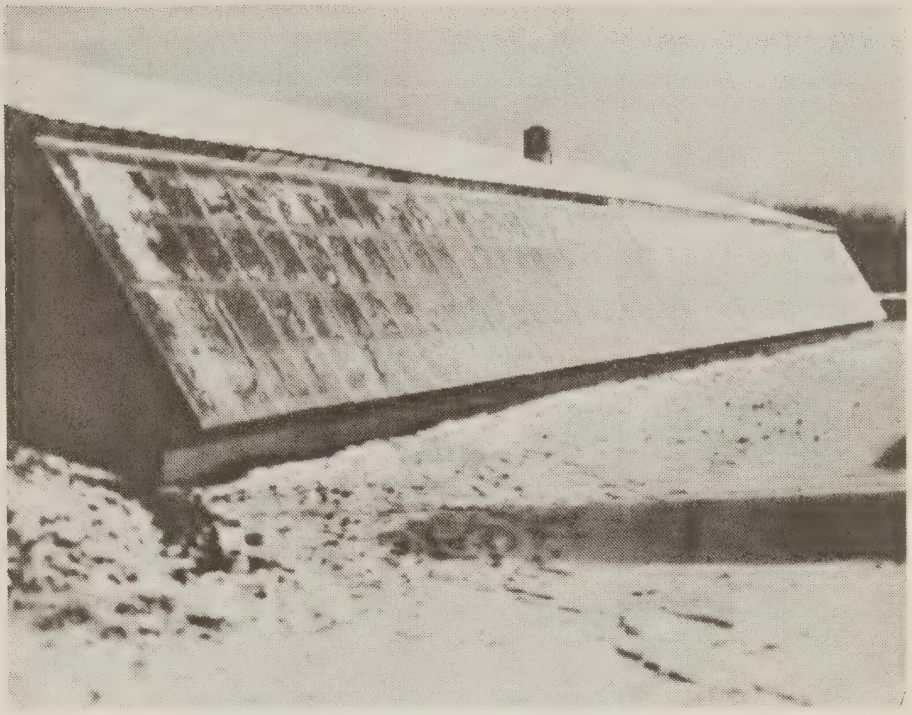
UNIT O

A COMBINATION SWINE FARROWING-NURSERY COMPLEX located in Beltrami County Minnesota with valid collection data since January, 1981 featuring:

838 sq. ft. solar collector.

1,067 cu. ft. of rock storage.

3,136 sq. ft. of building



SYSTEM DESCRIPTION: This 30 sow - 200 pig complex has two heating systems: 1) 85,000 btu/hr. wood fired forced air furnace, 2) a one-hundred-twelve foot by seven-and-one-half foot solar collector attached to the south side of the building. The solar collector has a single glazing of Filon tilted at sixty-two degrees from horizontal with air intake vents located on the lower edge of the collector. The absorber has three layers of black annodized aluminum window screen, which acts as a low mass Hohraum, and a flat black painted plywood back wall. 1,067 cubic feet of rock partially fill the cavity between the south wall of the building and the absorber and is used as solar storage. The solar systems rock storage area is connected to the plenum on the wood furnace by a duct between the two so that the 1460 c.f.m. blower on the wood furnace also pulls air through the solar collector. Ducting from the plenum of the wood furnace runs into both the nursery and farrowing rooms for air distribution.

COST: The cost of adding the solar collection and storage system to this newly constructed swine farrowing-nursery complex breaks down as follows:

	COSTS	COST PER SQ. FT.
Solar collector	$ 2110.79	$ 2.48
Solar, rock bed, storage	839.71	0.99
Labor	2316.50	2.73
TOTAL	$ 5267.00	$ 6.20

PERFORMANCE SUMMARY: This solar collection system captured a nominal 47% of the incident solar radiation that fell on it which would relate to a savings of approximately $1,000 had electric resistance heating been used, (at $0.05/kilowatt-hour).

COMMENTARY: This is a solar collection system that could be easily retrofitted on most builings. However, care should be taken to overcome this systems two major problems; air leaks and snow coverage.

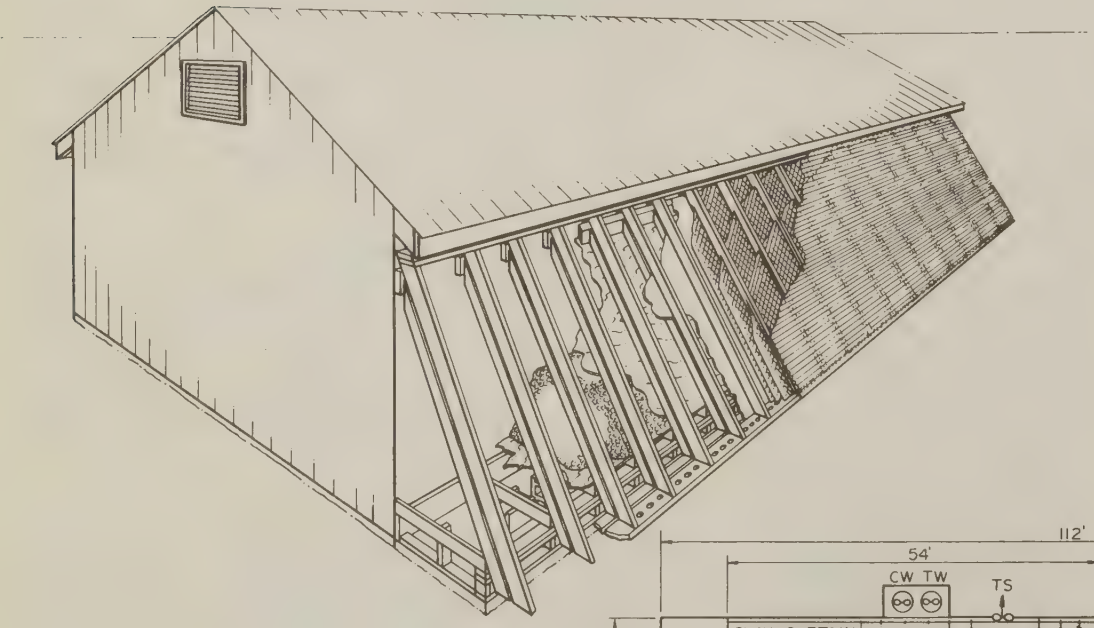
Because this collector is so large, (838 sq. ft.) numerous air leaks occurred in the first year that made controlling air distribution through the collector and rock storage impossible, this reduced

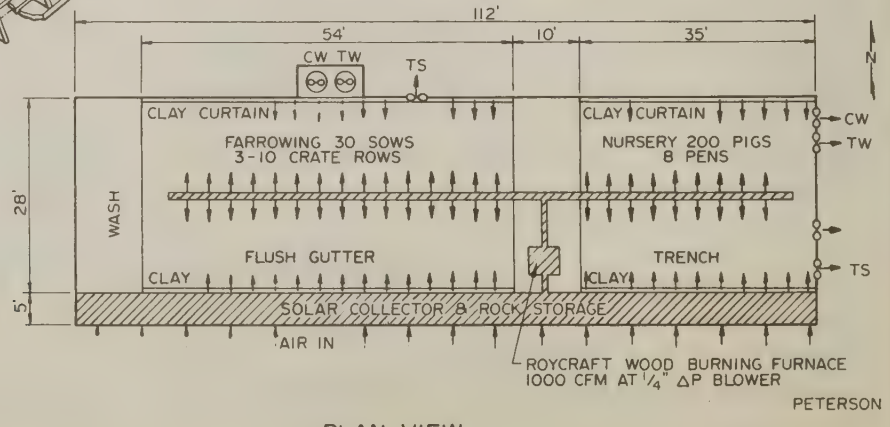
the system's performance markedly. After analysis of the first year's data was completed the solar collection system was resealed and performance increased.

A perpetual problem with this system is snowfall. The sixty degree angle that the collector is sloped at is not enough to keep the glazing free of snow during the winter months. Therefore the collector must be cleaned frequently during the winter to allow solar radiation to pass through to the collector.

SYSTEM PERFORMANCE FROM OCT '81 TO APR '82

MONTH	SOLAR HEAT COLLECTED (Kilowatt-hours)	TEMP. OUTSIDE (degrees celsius)	TEMP. OUT OF COLLECTOR	COLLECTOR EFFICIENCY
OCT	7104.37	6.1	17.4	40.7
NOV	-	-	-	-
DEC	-	-	-	-
JAN	2913.75	-22.1	-17.5	55.0
FEB	2788.65	- 6.8	- 1.9	64.1
MAR	3918.29	- 6.9	- 0.7	49.9
APR	6172.22	- 1.9	8.3	45.2
AVERAGE	4579.46	- 6.3	1.1	47.1





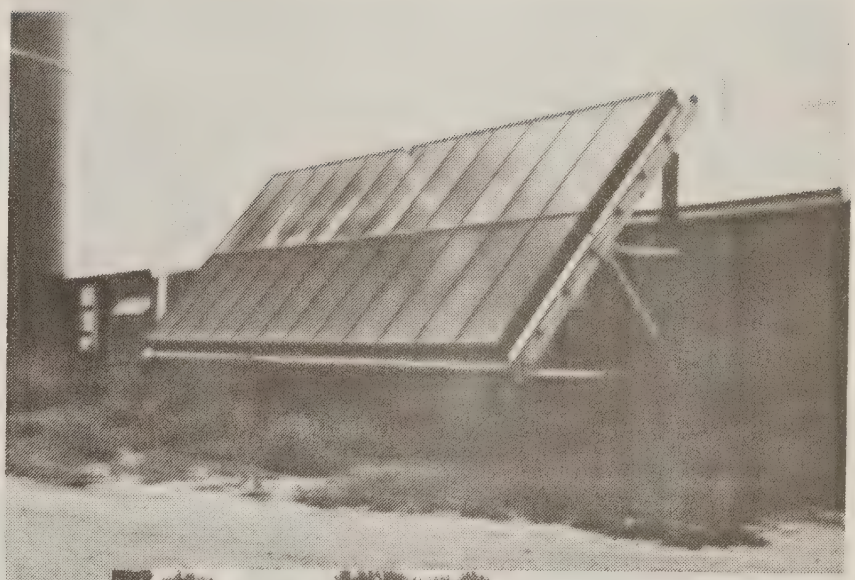
PLAN VIEW
SCALE 3/4" = 10'

DAIRY FARMS in Millelacs and Dodge Counties Minnesota with valid collection data since January, 1981 featuring:

458 sq. ft. and 191 sq. ft., respectively, of flat plate air collectors.

Rock box storage, (at both sites).

Hot water and space heat for both milking parlors.





SYSTEM DESCRIPTION: These dairy farms both use commercially produced flat plate collectors to supplement gas furnaces in heating a milking parlor at one farm, calf housing at the other, and to pre-heat water for the water heaters at both farms.

The collection system, designed by "Surge", incorporates two loops in its air flow cycle. One, the collection loop, flows from the air handler, to the rock bed storage, to the flat plate collectors, and back to the air handler. The other, heating loop, flows through the rock storage, the gas furnace blower, the heated room, and back to the storage. The heat exchanger, for the hot water pre-heat system, is found between the air handler and the rock storage and experiences air flow in either loop. Air flow through the loops is directed by motorized dampers that are controlled by temperature sensors in the system. The collectors themselves, are mounted at the south end of the barns, and inclined at approximately a 60 degree angle from horizontal.

COST: The cost of buying and constructing these solar collection systems was $13,500.62, or $70.65 per square foot, and $17,079.50, or $37.32 per square foot for the Dodge County and Millelacs County dairies respectively.

PERFORMANCE SUMMARY: Collection systems at both farms captured a nominal 30% of the solar energy available from September, 1981 to April, 1982. This amounted to a savings of approximately $1 in heat energy per square foot of collector area in comparison with propane at 65 cents per gallon.

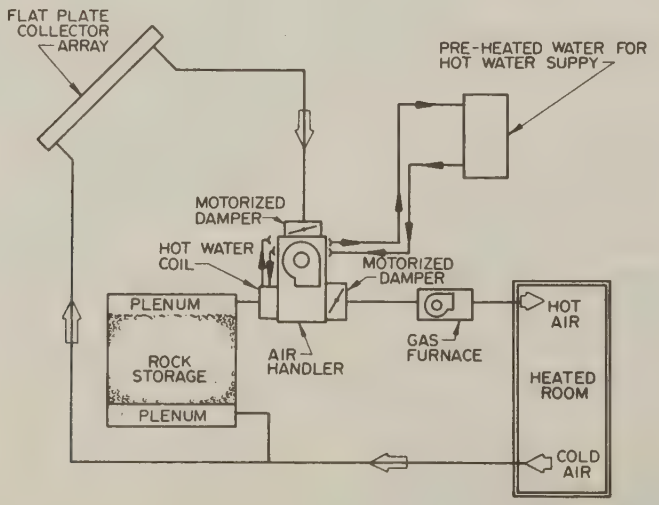
COMMENTARY: Solar collection system efficiences could be increased at these farms with more seasonal maintenance and better insulation. Periodic inspection of the rock box for small leaks is essencial as the infiltration of cold outside air into the storage system can seriously errode system performance. Also, the careful insulation of all air ducts pays off in decreased heat loss and increased efficiences.

458 sq. ft. COLLECTOR
SYSTEM PERFORMANCE FROM OCT '81 TO APR '82

MONTH	SOLAR HEAT COLLECTED (Kilowatt-hours)	TEMPERATURES OUTSIDE	IN COLLECTOR	OUT COLLECTOR (degrees celsius)	COLLECTOR EFFICIENCY
OCT	2668.56	14.4	20.3	24.9	33.9
NOV	3173.30	12.1	20.7	24.6	37.7
DEC	581.65	3.0	13.6	12.5	13.2
JAN	-	-	-	-	-
FEB	1857.06	4.0	16.6	18.6	26.8
MAR	2609.41	6.3	18.9	21.9	31.2
APR	2096.98	7.1	18.4	21.3	27.1
AVERAGE	2164.49	7.8	18.1	20.6	29.7

191 sq. ft. COLLECTOR
SYSTEM PERFORMANCE FROM SEPT '81 TO MAY '82

MONTH	SOLAR HEAT COLLECTED (Kilowatt-hours)	TEMPERATURES OUTSIDE	IN COLLECTOR	OUT COLLECTOR (degrees celsius)	COLLECTOR EFFICIENCY
SEPT	912.14	14.3	20.9	26.0	38.2
OCT	650.16	8.9	15.9	20.4	41.5
NOV	1376.58	5.9	14.9	25.1	48.2
DEC	37.81	-9.3	3.0	15.1	3.6
JAN	353.22	-15.3	-0.1	3.2	22.2
FEB	651.58	-8.3	5.5	10.3	27.0
MAR	866.67	-2.8	6.0	15.8	30.3
APR	649.28	3.9	14.1	21.5	24.2
MAY	648.72	11.9	19.0	25.0	26.8
AVERAGE	682.91	1.0	11.0	18.0	31.0



"SURGE" SOLAR COLLECTION & STORAGE SYSTEM

A SWINE FARROWING-NURSERY COMPLEX in FREEBORN County Minnesota operating since January, 1981 with:

1,760 sq. ft. roof collector.

Vertical black wall and black floor in attic serves as an absorber.

4,938 sq. ft., 4 farrowing rooms and 3 nursery rooms



SYSTEM DESCRIPTION: For space heating the farrowing-nursery complex has a liquid propane hot water furnace and a twenty foot by eighty-eight foot solar collector. The hot water furnace, rated at 150,000 B.t.u.'s per hour maximum, pumps hot water at approximately thirty-two gallons per minute through pipes in the floor. The forty degree south sloping roof was constructed with solar heating in mind. The structure forms a salt-box collector where the roof, on the south side, has been covered with a single layer of Filon fiberglass. The absorber for the system is a flat black vertical sheet rock wall built from the peak of the roof to the attic floor.

Ventilation air, passing through the attic, picks up heat and is drawn in the hallway, which acts as a plenum for the rooms. The air is then distributed through the building by the exhaust ventilation fans. This system has no storage facilities.

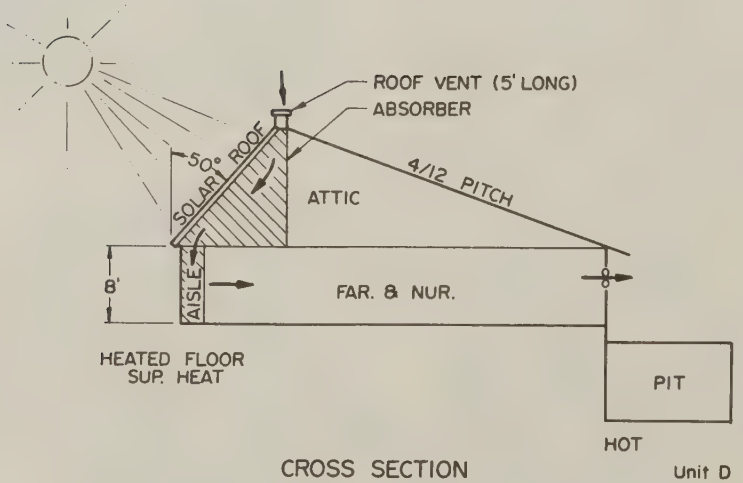
COST: The cost of this solar collection system was $9216.67 or $5.24 per sqare foot of collector area.

PERFORMANCE SUMMARY: The solar collection system at this farm provided a nominal 88% of the energy required for space heating the farrowing-nursery complex during the September, 1981 to May, 1982 heating season. However, it should be noted that the greatest source of heat energy in the building is the heat given off by the pigs themselves. During the same heating season the solar collector captured about 48% of the incident solar radiation that fell on it, and resulted in a savings of approximately $3,867.44 in propane, (at $0.65/gallon).

COMMENTARY: The evaluation of energy use in this multifan, (19), system is open to question since it was impossible to sense and record air leakage into the common hallway-plenum. Air velocity tests were performed to determine the flow through the collector, however, these tests represented the flow during the tests only. A fan which burned out was replaced with a locally available fan with different static pressure characteristics, and leakage by this fan was observed.

SYSTEM PERFORMANCE FROM SEPT '81 TO MAY '82

MONTH	SOLAR HEAT COLLECTED (Kilowatt-hours)	TEMPERATURES (degrees celsius) OUTSIDE	OUT COLLECTOR	INSIDE	COLLECTOR EFFICIENCY
SEPT	19990.80	6.9	11.9	17.6	62.6
OCT	11910.70	3.8	6.4	18.9	47.9
NOV	16058.60	0.3	4.0	18.3	62.4
DEC	7820.15	-13.7	-10.8	15.2	42.4
JAN	3544.09	-22.2	-19.7	14.5	20.1
FEB	12674.80	-12.7	-8.0	15.1	48.1
MAR	10934.80	- 4.8	- 0.1	15.7	38.2
APR	14019.30	- 1.4	4.0	16.5	42.3
MAY	15072.10	12.4	16.5	20.9	54.3
AVERAGE	12447.26	- 3.5	0.5	17.0	47.8%



CROSS SECTION Unit D

A SWINE NURSERY in LeSueur County Minnesota with valid monitoring data since January, 1981 featuring:

1926 sq. ft. of roof collector, (retrofitted to the building).

No storage capabilities.

480 sq. ft. of swine nursery to heat with an approximate A.U. value of 156 Btu/hr.-degree F.



SYSTEM DESCRIPTION: This farm's solar collector is the entire 4/12 pitched roof of the twenty-four foot by sixty foot combination swine nursery-grower building. The structure is oriented with the roof ridge running north to south with only the 480 sq. ft. nursery room, on the south end of the building, heated by the solar collector. The collector was retrofit to this building by fastening sheets of translucent Filon fiberglass several inches above and parallel to the metal roof which is dark blue in color. The building's ventilation system causes air to be drawn through the intake vents along the roof eaves on either side of the building. The air picks up heat from the absorber, (the original metal roof), and flows to the peak where it enters the building's attic through the vented roof ridge. Ducting in the ceiling of the nursery allows the heated air to enter that room and eventually be exhausted through the pit fan.

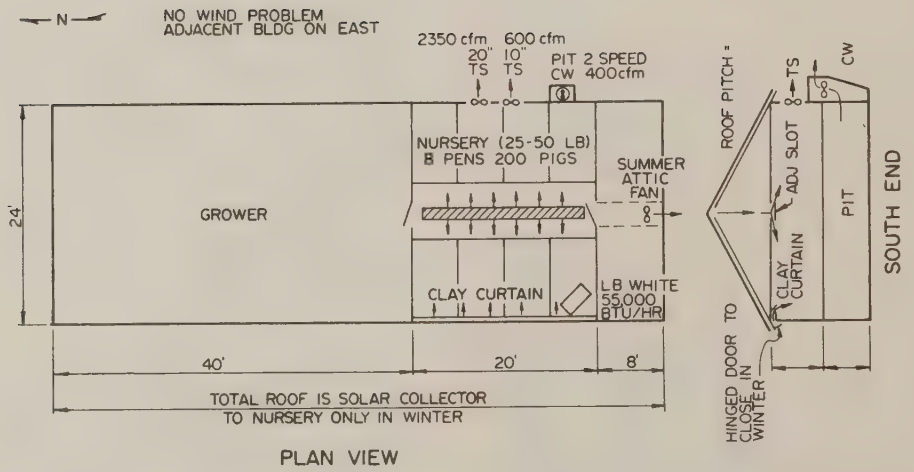
COST: The cost of retrofitting this building with this solar collection system came to approximatly $4000, for a cost of $2.08 per square foot of collector area.

PERFORMANCE SUMMARY: This solar collector captured a nominal 12% of the available solar energy from October, 1981 to May, 1982. This represents about 48% of the nursery's heating requirements and would compare to approximatly $600 in propane (at 65 cents per gallon) or $875 in electrical energy (at 5 cents per Kilowatt-hour). Collector output for the 1981-1982 heating season was about 31 cents per sq. ft. of solar collector area.

COMMENTARY: The solar collector at this farm is simple enough in design that it could be retrofitted to most livestock buildings. However, two improvements on the system could be made that would help to boost performance; 1) orientation of the building to provide southern exposure, (rather than east-west as it is in this case), 2) addition of a solar storage system so that heat could be stored until needed, (during the cooler night temperatures).

SYSTEM PERFORMANCE FROM OCTOBER 1981 TO MAY 1982

MONTH	AVERAGE TEMPERATURES (degree celsius) OUTSIDE	OUT-COLLECTOR	INSIDE	SOLAR COLLECTED (kilowatt-hours)	PROPANE PURCHASED (kilowatt-hours)	COLLECTOR EFFICENCY
OCT	5.9	11.6	19.4	1298.5	139.6	10
NOV	8.0	7.6	22.1	1619.5	951.0	16
DEC	-8.0	-4.0	21.0	687.3	1014.1	23
JAN	-12.9	-5.9	18.4	1255.0	3715.7	11
FEB	-17.5	-11.1	22.8	1005.1	2856.2	11
MAR	0.5	10.1	22.6	1659.1	794.3	6
APR	4.9	15.3	24.2	2685.2	1404.1	9
MAY	14.4	25.2	24.8	7266.7	298.5	18
AVE	-2.4	6.1	21.9	2184.5	2404.1	12



PLAN VIEW

PROJECT OVERVIEW

In the Spring of 1979, the University of Missouri in cooperation with USDA, USDOE, and 11 farm operators initiated a $299,000.00 project to investigate and demonstrate the feasibility of offsetting some of agriculture's needs for fossil fuel with solar energy. Funding for the project was provided from the following sources:

USDA/USDOE	40%
UMC Extension	40%
Cooperators	20%

Among the cooperating farmers were 6 swine producers, 3 dairymen, and 2 poultry producers.

Construction of 11 units was completed during the Fall of 1980. A total of 16,032 square feet of collector were constructed at a cost of $88,239.00. Collector units ranged in size from 120 square feet up to 5,000 square feet and costs ranged from $1.11 to $47.55 per square foot, depending on system complexity.

System performance was measured during the Winters of 1980 and 1981 with specific results reported later in this document.

The project provided a considerable amount of information which was used as the basis for numerous educational activities in support of the Missouri Extension program. Among these were the following:

1. Seminars on solar design and operation for local, state, and national meeting of farm builders involved in construction of solar units.
2. In depth training sessions for area Extension staff.
3. Development of specific design procedures for solar systems used for water heating and ventilation air preheat.

MISSOURI SOLAR LIVESTOCK DEMONSTRATION PROJECT SUMMARY

COOPERATOR	BUILDING TYPE	NEW OR RETROFIT	COLLECTOR SIZE SQ. FT.	TYPE	STORAGE	COST TOTAL	COST PER SQ. FT.	ENERGY USE	REMARKS
G. Dressendofer	Farrowing	New	1920	Air	Rock	17,310.	9.01	Vent Pre-heat	Summer Cooling Option
L. Himmelberg	Swine Nursery	New	320	Air	Conc Block	3,868.	12.08	Vent Pre-heat	Earth Contact Building
G. Pogue	Swine Nursery	New	1680	Air/ Water	Water	10,488.	6.24	Vent Pre-heat Floor Heating	
A. Adam	Farrowing/ Nursery	New	2000	Air	None	6,136.	3.06	Vent Pre-heat	Commercial Package System
V. Hannah	Farrowing/ Nursery	New	1300	Air	None	1,821.	1.40	Vent Pre-heat	
G. Sandidge	Farrowing	New	1392	Air	Conc Block	18,363.	13.19	Vent Pre-heat	Summer Cooling Option
G. Snow	Milking Center	Retrofit	120	Water	Water	5,539.	46.15	Water Pre-heat Space Heat	Also Includes Milk Compressor Heat Recovery System
D. Martin	Milking Center	Retrofit	120	Water	Water	5,707.	47.55	(SAME AS G. SNOW FARM)	
F. Martin	Milking Center	Retrofit	180	Water	Water	4,770.	26.50	(SAME AS G. SNOW FARM and D. MARTIN FARM)	
L. Prier	Poultry Brooding	Retrofit	2000	Air	Rock	8,661.	4.33	Vent Pre-heat	
C. M. Price	Poultry Brooding	Retrofit	5000	Air	Rock	5,576.	1.11	Vent Pre-heat	
			16,032			88,239.	5.50		

4. Informational meetings for representatives of the farm credit industry in the state.
5. Facility tours for farmers interested in solar applications.

Conclusions reached as a result of this project include the following:

1. Preheating of ventilation air appears to be the most feasible application for solar energy in livestock production.
2. Solar systems need heat storage in order to effectively utilize solar energy in modern livestock buildings. Well insulated animal housing units do not have a high demand for heat energy during daytime hours in Missouri. Energy needs occur at night when outside temperatures are at a minimum and direct solar is not available.
3. The so called "attic" or "whole-roof" collector systems are lowest in cost and also have very low efficiencies.
4. Solar systems are not economically feasible alternatives for providing hot water used on dairy farms. Currently available milk heat recovery systems will provide needed water at a more economical cost.
5. Construction of solar systems requires greater than normal care to insure against fluid leakage and maintain maximum system performance. Most farm building contractors will require some retraining in order to accomodate these needs.
6. The most feasible systems demonstrated are those used to preheat ventilating air in poultry brooding facilities. The reason for this is the relatively high demand for supplemental energy on a year round basis.



Richard E. Phillips, Project Director
September 1982

INSTRUMENTATION

Information on performance of the solar systems was collected and processed utilizing the following equipment and methodology.

Data Logging

Two Campbell Scientific Model CR-5 and one Model CR-21 Recorders were utilized to collect data. These units are solid state devices with battery operated power supplies and were purchased in relatively tight cases which were able to withstand the rigors of agricultural environment. The units were programmed to output data to standard audio cassette tape on an hourly basis.

Temperature Measurement

Standard copper-constantan thermocouples were used with the CR-5 recorders and thermistor based sensors were used with the CR-21. Locations where temperature were expected to vary widely during the interval between recordings were input to the data loggers through integrating modules - which yielded hourly averages.

Solar Radiation

Incident radiation in the plane of the collector was measured using silicon pyranometers manufactured by LiCor (Model LI-200-S). Output from the silicon cells was input to the recorders through the integrating channels. Output from the silicon cells was compared to data collected by the NOAA weather station at Columbia prior to the test and was found to be in close agreement.

Fluid Flows

Air flow was measured using an Alnor Hot Wire Anemometer. Systems using water circulation through the collector were calibrated using a physical measurement and a stop watch. Hot water usage on the dairy farms was measured with a standard dial type water meter. On-off operation of fluid handling devices was input to the data loggers through a signal conditioner which produced a constant millivolt signal during operation.

Data Processing

Cassette tapes from the recorders were processed through a computer interface manufactured by Campbell directly into a Radio Shack TRS-80 Microcomputer. The computer was programmed to output hourly data and daily summaries of system performance.

INDIVIDUAL FARMS

The following pages contain information on individual farms cooperating in this study. Included is material on system design, construction, and performance.

1. Glenn Dressendofer, Route 1, Vichy, Missouri.
2. Leo Himmelberg, Glasgow, Missouri.
3. Gene Pogue, Route 3, Clinton, Missouri.
4. Alan Adam, Route 2, Vandalia, Missouri.
5. Veldron Hannah, Route 2, Bolckow, Missouri.
6. Gerald Sandidge, Marshall, Missouri.
7. Gale Snow, Wheatland, Missouri.
8. Donald Martin, Route 3, Appleton City, Missouri.
9. Freddie Martin, Humansville, Missouri.
10. Leslie Prier, Newtonia, Missouri.
11. C. M. Price, Stark City, Missouri.

FARM NO. 1

I. Glenn Dressendofer, Route 1, Vichy, Missouri, operates a 185 sow farrow-to-finish swine operation at the location of this project. He specializes in the production of breeding stock which are marketed throughout the Western Hemisphere.

II. The solar demonstration project at this site was integrated into the construction of a new farrowing building. Specific goals of the solar system design included the following:

1. Provide heat collection and storage to be used in ventilation air preheating for the building.
2. Develop a system which incorporated air recirculation through the heat storage.
3. Utilize storage to provide summer cooling by using evaporative cooling and circulation of night air through storage.

III. The new farrowing unit is a 33' x 105' building with a central office area and four 8 sow farrowing rooms. The farrowing rooms are separated from each other by poured concrete bins filled with a total of 160 tons of rock used for heat storage.

Ridge line of the building runs East-West and the entire South slope of the roof is covered with a suspended plate type collector. Roof purlins were covered with polystyrene insulation and a layer of black painted plywood was used as the suspended plate. The roof was surfaced with tedlar coated. fiberglass reinforced plastic.

Air is circulated from the roof collector through the rock storage and back. Make-up air required to supply the ventilation system is introduced directly into the circulating stream from outside the building

so that contaminated air is not forced through the storage or collector.

During Summer months, cool night air is used to reduce storage temperature. In the daytime, outside air is drawn through the storage by the ventilation system. There is also a provision to spray water over the top of the rock storage to provide added cooling of the ventilating air by evaporation.

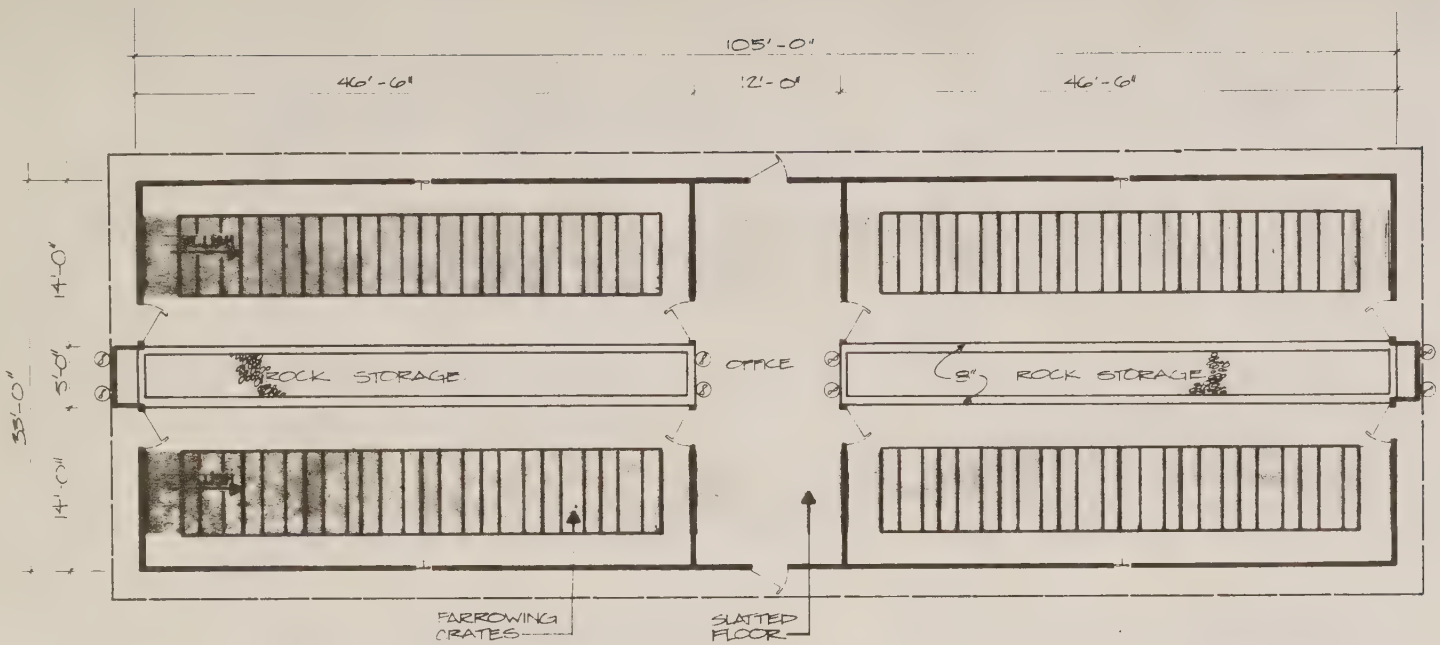
IV. This system was fully completed and operational in May 1980 at a cost of $17,310.00 or approximately $9.00 per square foot of solar collector.

V. Total heat demand for this structure is approximately 900 Btuh per degree temperature difference between inside and outside. When operated at full capacity, animal heat is sufficient to maintain a temperature difference of approximately 22 degrees F. Inside temperature is maintained at an average of 70^{o} F during the heating season.

Data were collected on this system during November-December 1979, August 1980, and January 1982. Representative values of performance are shown below.

Solar Heating-Dressendofer Building

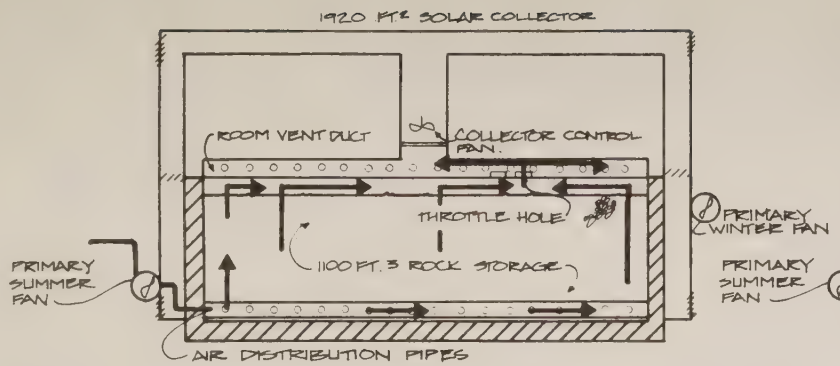
	Data Collection Period	
	Nov-Dec 1979	January 1982
Solar Radiation Average Btu/ft^2 - day	670	637
Heat Added to Ventilation Air 1,000 Btu/day	415	600
Solar System Efficiency	.31	.47
Average Outside Temperature (^{o}F)	46	30
Average Inside Temperature (^{o}F)	70	70



NORTH.

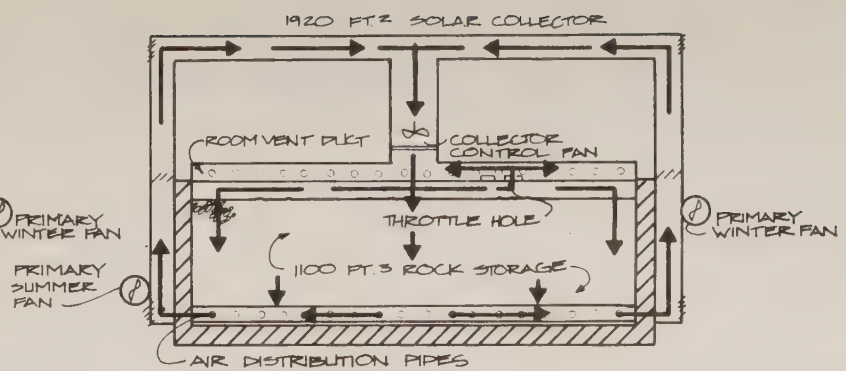
SOLAR DEMONSTRATION PROJECT
DRESSENDOFFER FLOOR PLAN

AGRICULTURAL ENGINEERING DEPT. UNIVERSITY OF MISSOURI - COLUMBIA.			DRW. PRJ. 34-726-C2
DATE: 5.9.80 SCALE: 1/8" = 1'-0"	APPROVED: REP	DRAWN: LRK	SHEET: 1 OF 2



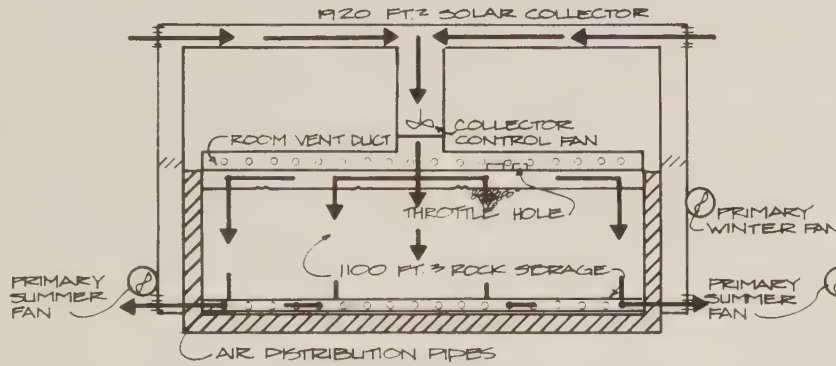
OPERATIONAL MODE: SUMMER DAY

- PRIMARY SUMMER FAN PROVIDES ROOM VENTILATION THROUGH COOLED ROCK.



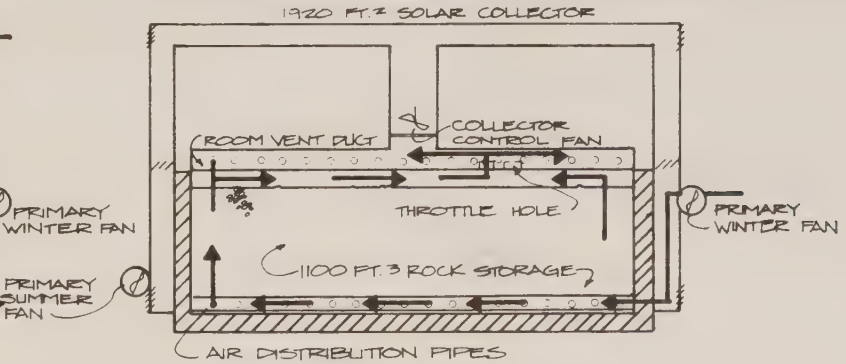
OPERATIONAL MODE: WINTER DAY (SOLAR)

- COLLECTOR CONTROL FAN COLLECTS HEAT FOR ROCK STORAGE AND VENTILATES THROUGH THROTTLE SHUTTER
- SECONDARY FAN IN WALL OF EACH ROOM VENTILATES WITH AMBIENT AIR. (IF RM. TEMP. > SET PT.)



OPERATIONAL MODE: SUMMER NIGHT

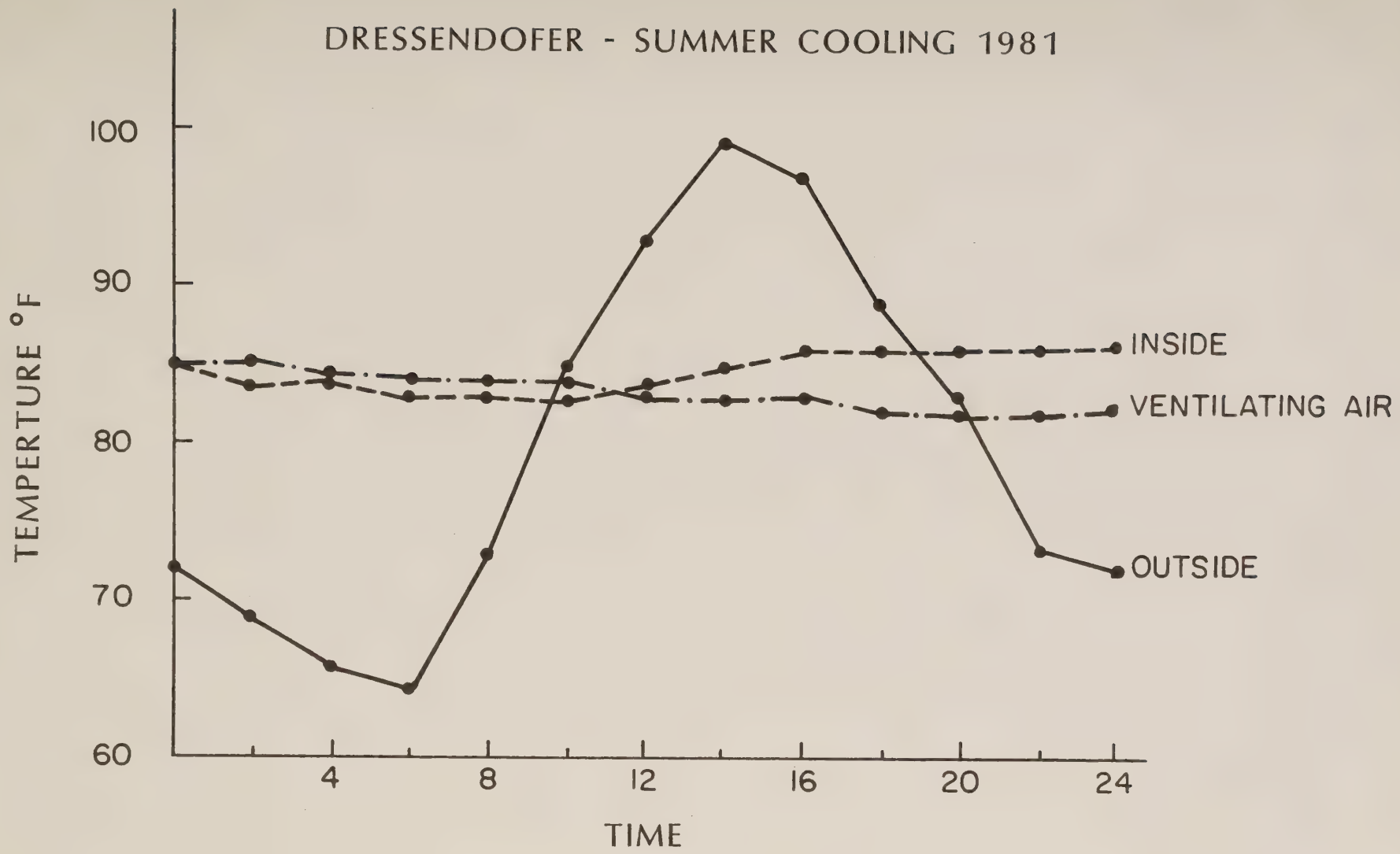
- COLLECTOR CONTROL FAN CONDITIONS ROCK FOR THE NEXT DAY.
- SECONDARY FAN PROVIDES ROOM VENTILATION WITH AMBIENT AIR.



OPERATIONAL MODE: WINTER NIGHT OR NON-SOLAR DAY

- PRIMARY WINTER FAN PROVIDES VENTILATION THROUGH ROCK STORAGE.
- SECONDARY FAN IN WALL OF EACH ROOM VENTILATES WITH AMBIENT AIR. (IF RM. TEMP. > SET POINT.)

SOLAR DEMONSTRATION PROJECT DREESSENDOFFER SCHEMATIC			
AGRICULTURAL ENGINEERING DEPT. UNIVERSITY OF MISSOURI - COLUMBIA			DRW. PRJ. 34-726 C2
DATE: 5.9.80 SCALE: NONE.	APPROVED REP	DRAWN: LRK	SHEET: 2 OF 2



TYPICAL SYSTEM PERFORMANCE IN COOLING MODE

Summer Cooling	August 1980	Dressendofer Building
		Average Daily High Temperature ^{o}F
Outside Air		98
Inside Room		85
Rock Storage		78
Ventilating Air		82

Proper management of a swine farrowing unit requires the use of some type of supplemental heat to "spot heat" the area where baby pigs are maintained for the first few days of their lives. In this facility, spot heating was accomplished by the use of 250 watt radiant type heat lamps. Energy input by these heat lamps plus the solar contribution was sufficient to maintain winter temperatures at the desired level at all times. No additional energy was required to maintain desired ambient temperature.

This building heavily insulated and as such, does not have a high demand for supplemental energy for heating. Because of this, it is not expected that the solar system will pay off in terms of reduced energy usage. The owner is generally satisfied that the system is operating as intended and that aminal performance has been improved.

The system as designed and installed at the Dressendofer farm is the most complex of all the demonstration systems in Missouri. It has also become evident that proper operation of the system will require more than the casual management which most farmers allocate to environmental control systems.

Problems encountered during construction and operation include the following:

1. Failure of the contractor to recognize and accomodate the system's need for tight construction resulted in air leakage which seriously eroded system performance.
2. The expanded polystyrene insulation beneath the suspended plate has failed in several locations, requiring frequent repair to maintain the integrity of the air channel. This material should be avoided in construction of future units.

FARM NO. 2

I. Leo Himmelberg, Glasgow, Missouri, operates a 236 acre crop and livestock farm at the site of this demonstration. The swine operation consists of a 50+ sow farrow-to-finish production unit.

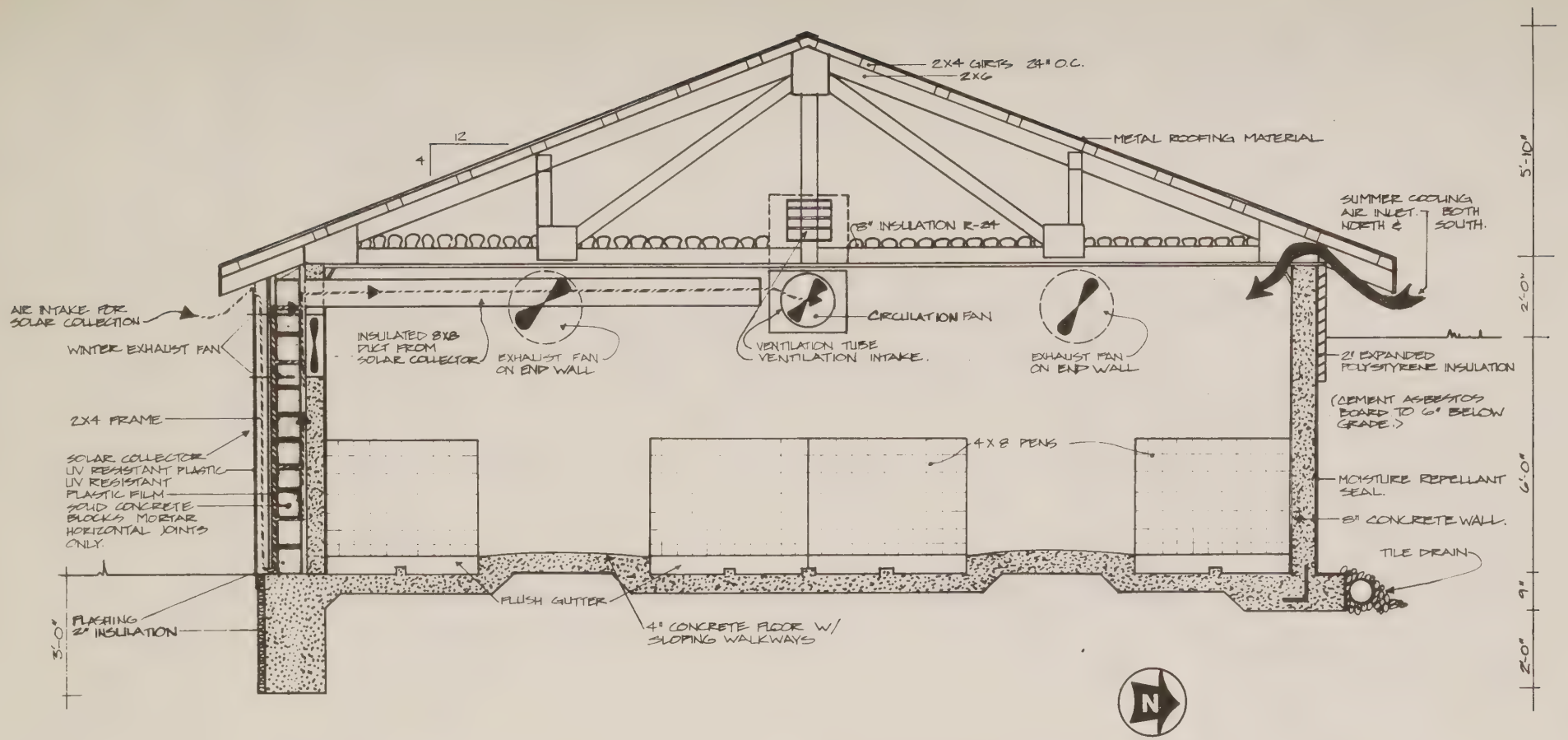
II. The solar demonstration unit was attached to a new swine nursery building. The main objective of the project was to supply energy for preheating of ventilation air.

III. A 28' x 48' building was constructed to house 200 nursery pigs (400 if double decking is installed). The building is of poured concrete construction with 3 walls recessed nearly full height into the ground. The fourth wall, which faces South, was equipped with a K-State type solar collector-storage wall.

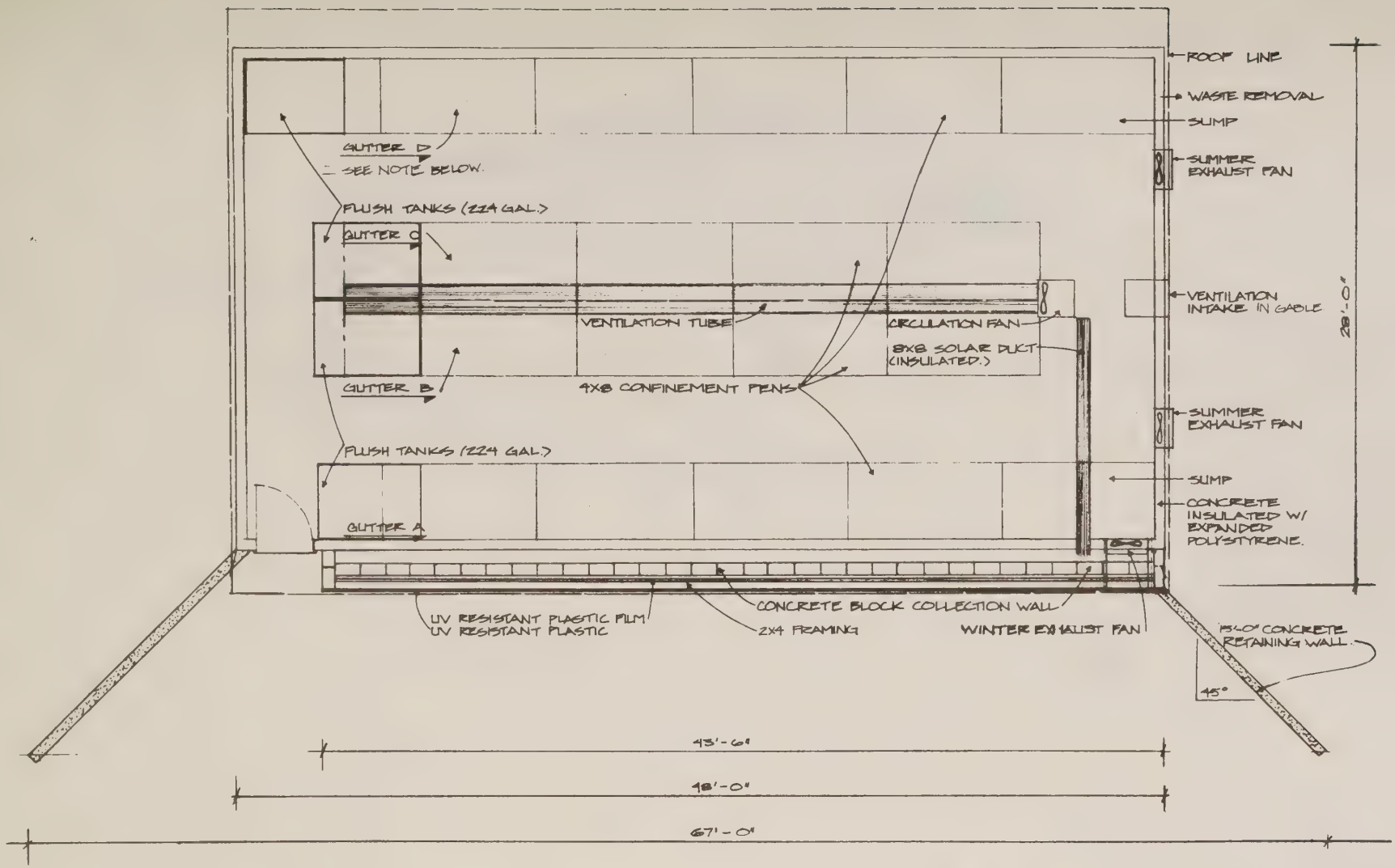
Ventilation air is drawn into the system between the two layers of plastic covering the collector wall, through the concrete block storage unit, and discharged at the inlet of the recirculating fan-tube ventilating unit inside the building.

Collector size was limited by overall building size. During December, it is expected that the system could supply approximately 25 percent of the supplemental heat needs for the building.

IV. The 320 square foot collector storage unit was constructed at a cost of $3,868.84 or $12.09 per square foot. It was placed in operation in early March of 1980.



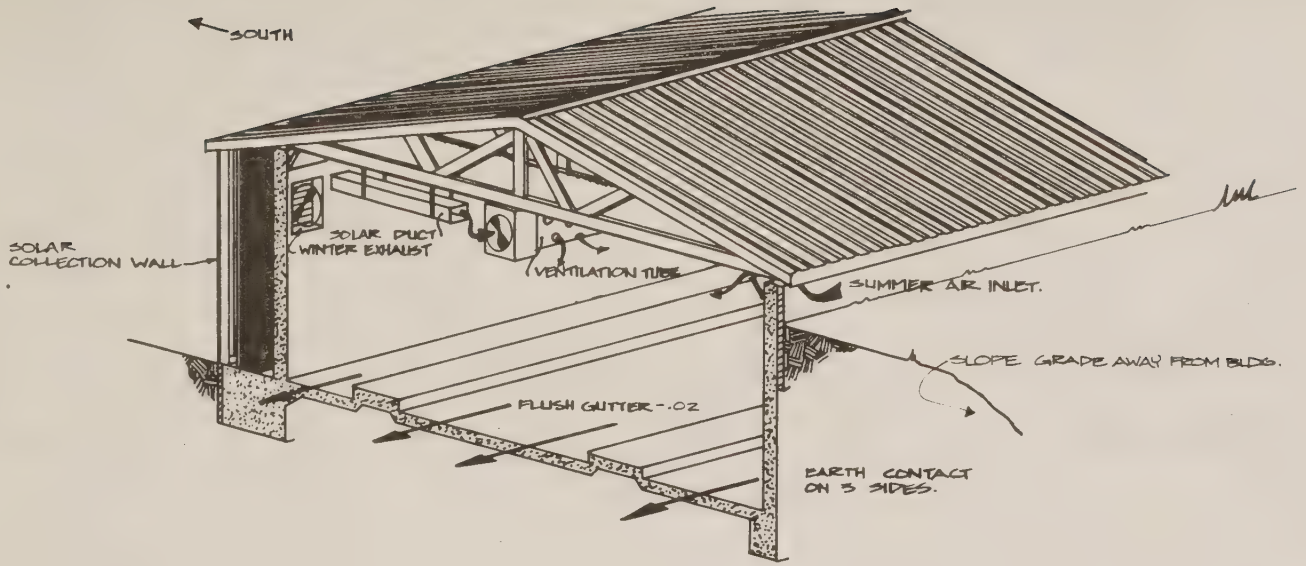
SOLAR DEMONSTRATION CROSS SECTION · HIMMELBERG · NURSERY			
AGRICULTURAL ENGINEERING DEPARTMENT UNIVERSITY OF MISSOURI – COLUMBIA			DWG/PRJ 82-726-C3
SCALE: ½"=1'-0" DATE: 7/16/79 REVISED: 3/7/80.	APPROVED: REP	DRAWN BY LRK	SHEET: 1 OF 3



GUTTERS A, B, C, D. = SLOPE .02
(1/4" PER FOOT OR 1'-0" IN 50'-0")

NORTH

SOLAR DEMONSTRATION FLOOR PLAN · HIMMELBERG · NURSERY			
AGRICULTURAL ENGINEERING DEPARTMENT UNIVERSITY OF MISSOURI - COLUMBIA			DWG/PRJ. 32-726-C 3
SCALE: 1/4"=1'-0" DATE: 7/16/79 REVISED: 3/7/80	APPROVED: REP	DRAWN BY: LRK	SHEET: 2 OF 3



NOTES ON SYSTEM OPERATION

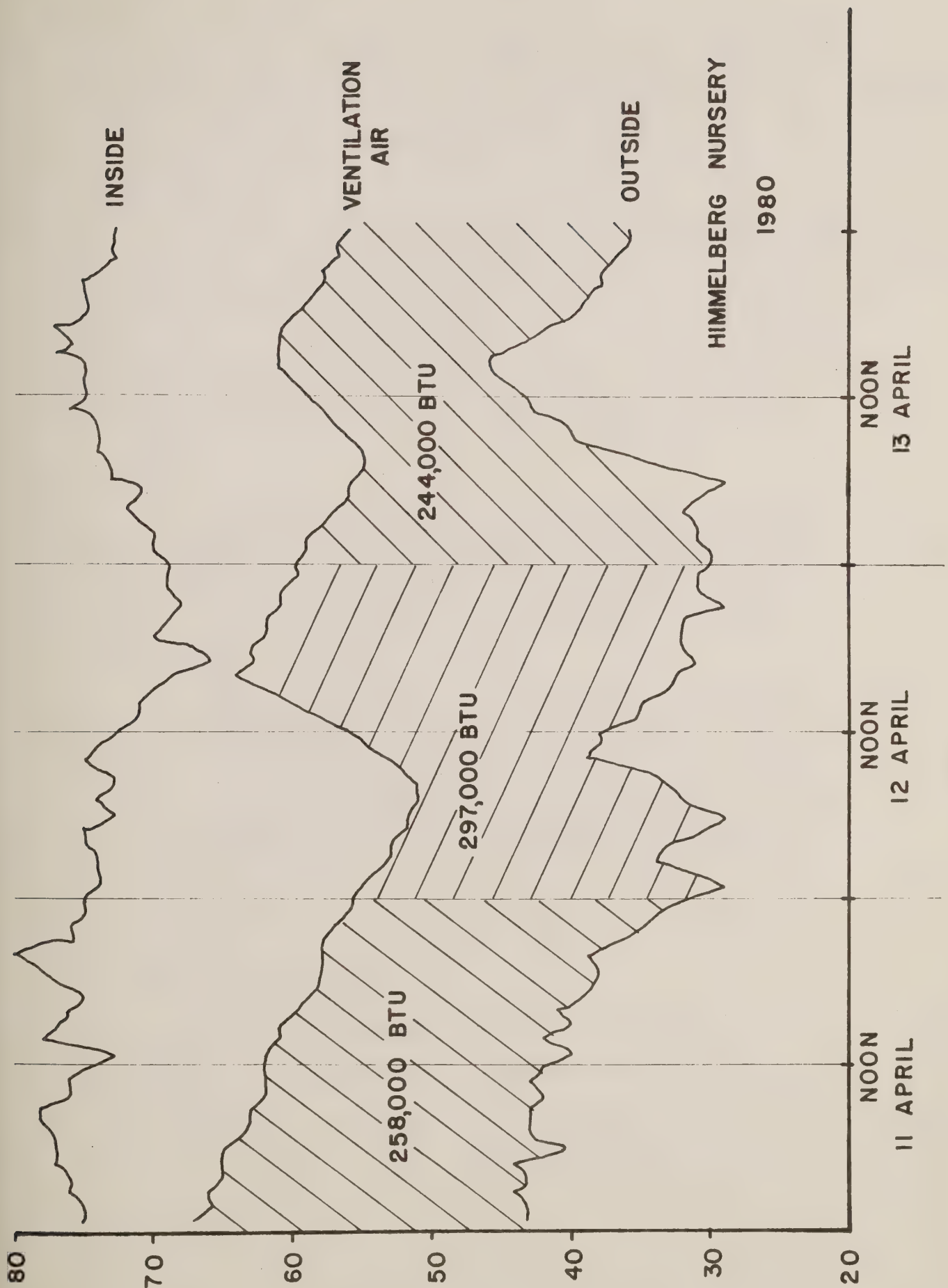
1. FAN FROM SOLAR COLLECTOR RUNS CONTINUOUSLY DURING WINTER AND PROVIDES MINIMUM VENTILATION RATE (WINTER) 3 CFM / PIG.
2.
2. WINTER EXHAUST FAN PROVIDES 15-20 CFM / PIG AND IS CONTROLLED BY THERMOSTAT SET 5° ABOVE SUPPLEMENTAL HEAT UNIT.

3. WINTER FAN AIR INLET IS LOCATED IN GABLE END OF BUILDING ADJACENT TO VENTILATION TUBE FAN. INLET IS CONTROLLED BY POWER LOUVER WHICH OPENS WHEN WINTER FAN COMES ON.

4. SUMMER FANS PROVIDE 40 CFM PER PIG. OPEN INLETS TO LET INTAKE AIR OVER THE TOP OF THE NORTH & SOUTH WALLS FOR SUMMER.

5. PROVIDE SUPPLEMENTAL HEATER FOR DAYS WHEN SOLAR WILL NOT PROVIDE ENOUGH FOR PROPER ROOM TEMPERATURE.

SOLAR DEMONSTRATION PERSPECTIVE · HIMMELBERG · NURSERY			
AGRICULTURAL ENGINEERING DEPARTMENT UNIVERSITY OF MISSOURI – COLUMBIA			DWG / PRJ: 32-726 C3
SCALE: NONE DATE: 7/16/79 REVISED 3/7/80	APPROVED: REP	DRAWN BY: LRK	SHEET: 3 OF 3


INSIDE
VENTILATION AIR
OUTSIDE
HIMMELBERG NURSERY
1980
258,000 BTU
297,000 BTU
244,000 BTU
80
70
60
50
40
30
20
DEGREES F
NOON
11 APRIL
NOON
12 APRIL
NOON
13 APRIL
TIME

V. The system has operated continuously since March 1980. Instruments measured performance during April and December of 1980 and in February 1982. A summary of these measurements is presented in the enclosed table.

The other table was developed using expected solar energy received on a vertical solar collector during the months from September to April. These figures appear to be conservative compared to the actual figures measured on this collector. These figures indicate an annual savings of about $530 with electricity rates of 5¢ per kilowatt hour.

Fixed costs of owning the collector, excluding interest, were estimated at $380. Subtracting this figure from the savings would give a net energy savings of $150 per year. This gives a 3.9% return on the investment of $3,868.84.

Investment credit can be reduced from the cost of the collector. With the energy credit, this amounts to 25%. This credit would be $967.21. This would reduce the cost of the collector to $2,901.63, giving a return of 5.2% on the investment with present energy costs.

Another way to look at investments in solar equipment is to determine the payback period with various rates of return and with escalating energy costs.

Using the investment of $3,868.84, the payback at 10% return on investment and an energy escalation rate of 10% is over 20 years. With the investment of $2,901.63 and the same values for percent return and energy escalation rate, the payback period would be between 15 and 20 years.

Performance of the system has been satisfactory except for some condensation on the exterior surface of the duct from the collector-storage unit. This duct should be insulated in order to prevent this problem in future designs.



The solar wall on the south side of Leo Himmelberg's swine nursery is providing a large part of his supplemental heat needs.

Summary of Measured System Performance - Himmelberg Nursery

	April 1980	December 1980	February 1982
Incident Radiation 1000 Btu/day	295	328	351
Energy Added to Building 1000 Btu/day	181	153	139
Average Daily Collection Btu/ft^2	567	476	436
System Efficiency	.61	.47	.40
Value of Energy Added ($/day)	2.67	2.24	2.04

Estimated Savings Per Year - Himmelberg Nursery

Month	Efficiency	Predicted Solar Radiation Vertical Surface x Expected Sun	Projected Capture	Projected Savings
		(1000 Btu/ft^2-day)	(1000 Btu/ft^2-day)	($/month)
Sept.	.57	975	555	78.08
Oct.	.53	1090	580	83.84
Nov.	.49	960	465	66.08
Dec.	.46	790	360	52.64
Jan.	.49	915	450	64.96
Feb.	.53	915	485	63.52
Mar.	.57	845	485	69.76
Apr.	.61	615	380	52.48
			TOTAL ANNUAL SAVINGS	$531.36

FARM NO. 3

I. Gene Pogue, Route 3, Clinton, Missouri, operates a 120 acre swine farm adjacent to the Truman Reservoir in West Central Missouri. They are presently involved in a herd expansion program aimed at a final production unit capable of handling 300 sows in a farrow-to-finish operation.

II. The solar demonstration unit on this farm was integrated into the construction of a new nursery building. Goals established for the system included the following:

1. Use solar heat to provide 40-50 percent of the December energy needs for a hot water floor heating system.
2. Preheat ventilation air during hours when solar energy is available.

III. The building design selected was for 28' x 120' clear span frame unit containing 10 pens on each side of the center alley. Pen floors are of concrete and are sloped toward flush type manure collection gutters located along outside walls. Ridge orientation of the building is East-West. Design capacity is 500 nursery pigs.

System management involves bringing sows and their litters to the building and placing 2 sows per pen in pens at the East end. When pigs are weaned, sows are removed and pigs are transferred to slightly larger pens at the West end.

Hot water heat is installed in the concrete floor of each pen in the area adjacent to the central alley. This system was designed to provide floor surface temperature of 95^{o} F.

Ventilation for the unit consists of a standard exhaust fan type system, with slot type inlets for fresh air. Control boards in the building soffit direct inlet air from the attic space during winter months and directly from outside during summer.

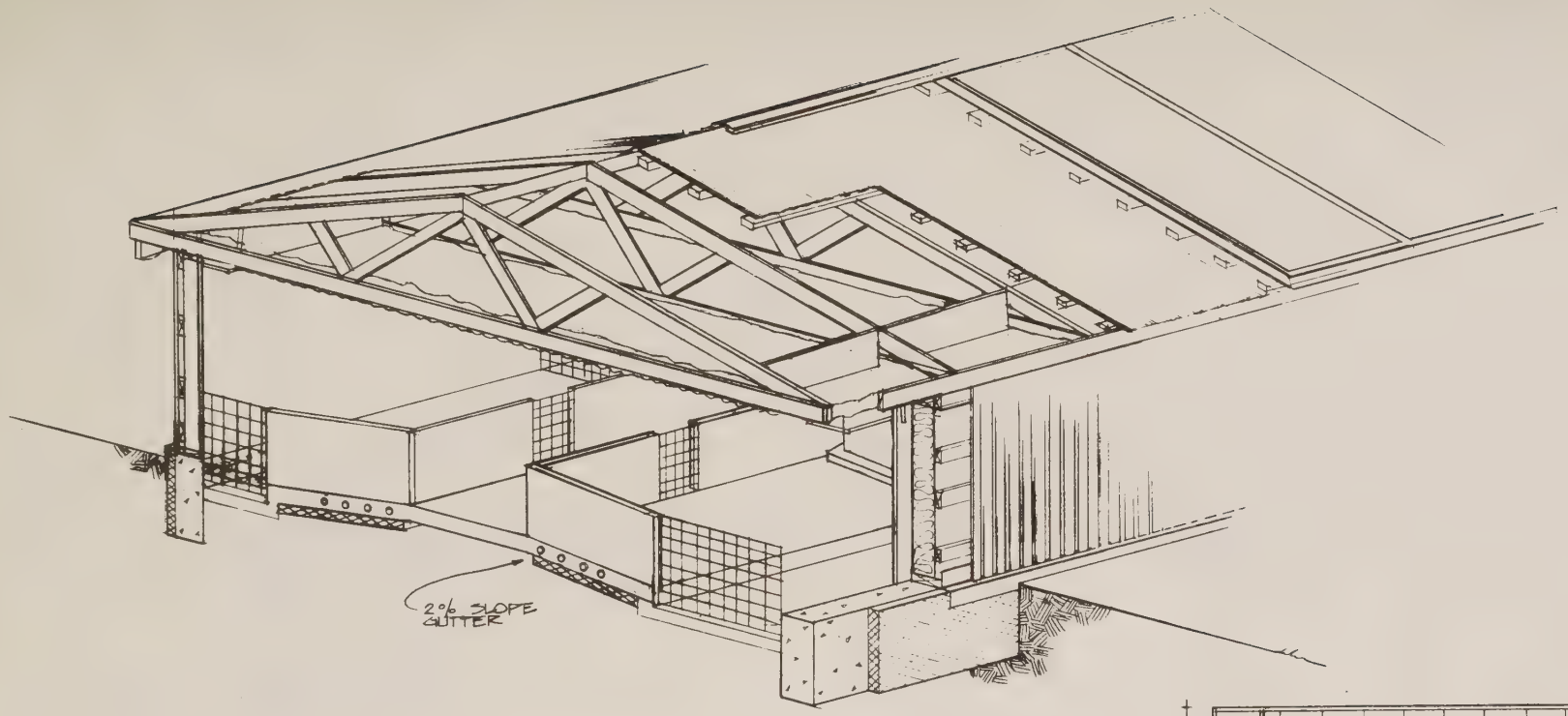
Heat loss calculations for the building indicated a need for approximately 34,000 Btu per day of supplemental heat for each degree F of temperature difference between inside and outside. The floor heating system requires an estimated 340,000 Btu per day to maintain the desired 95^{o} F surface temperature. Energy supplied to the floor heat system will maintain desired room temperature until outside temperatures drop below 18^{o} F.

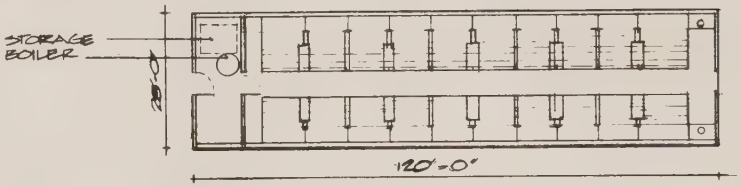
It was decided to use a water based, drain down type, flat plate collector to supplement the energy provided to the floor heat system by a conventional propane fueled hot water boiler. It was estimated that a 480 ft^2 collector would provide approximately 40 percent of the estimated daily energy needed during December. Using an estimated collection efficiency of 40 percent and a storage medium working range of 30^{o} F, a water storage of 1000 gallon will provide storage for one day's energy needs. During construction, a 2000 gallon tank was selected because of availability.

The water based collector unit and associated controls installed were as manufactured by Sunduit, Inc., of Virden, Illinois. The solar collector system was designed to charge the 2000 gallon insulated storage tank with heat. When storage temperature exceed 104^{o} F, stored hot water is used directly in the floor heat system. If storage temperature drops below 104^{o} F, it is by-passed and the conventional boiler heating unit takes over.

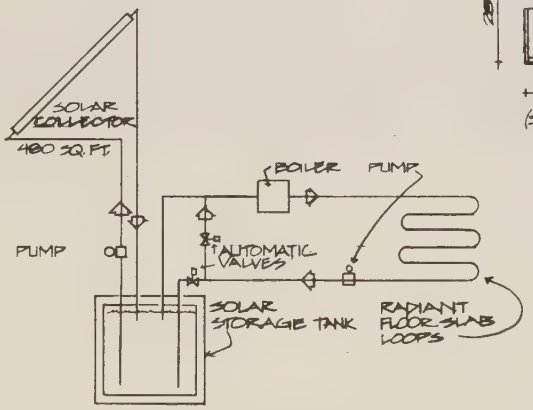
Collector plates were "built in" to the South slope of the building roof and the entire South slope was covered with glass fiber reinforced corrugated plastic. The 990 ft^2 of clear roofing, which did not cover the collector plates, admitted solar energy to the attic space which helped preheat incoming ventilation air during daylight hours.

IV. This system was completed in October 1980 at a total cost of $10,488.00 or an average of $6.24 per square foot.

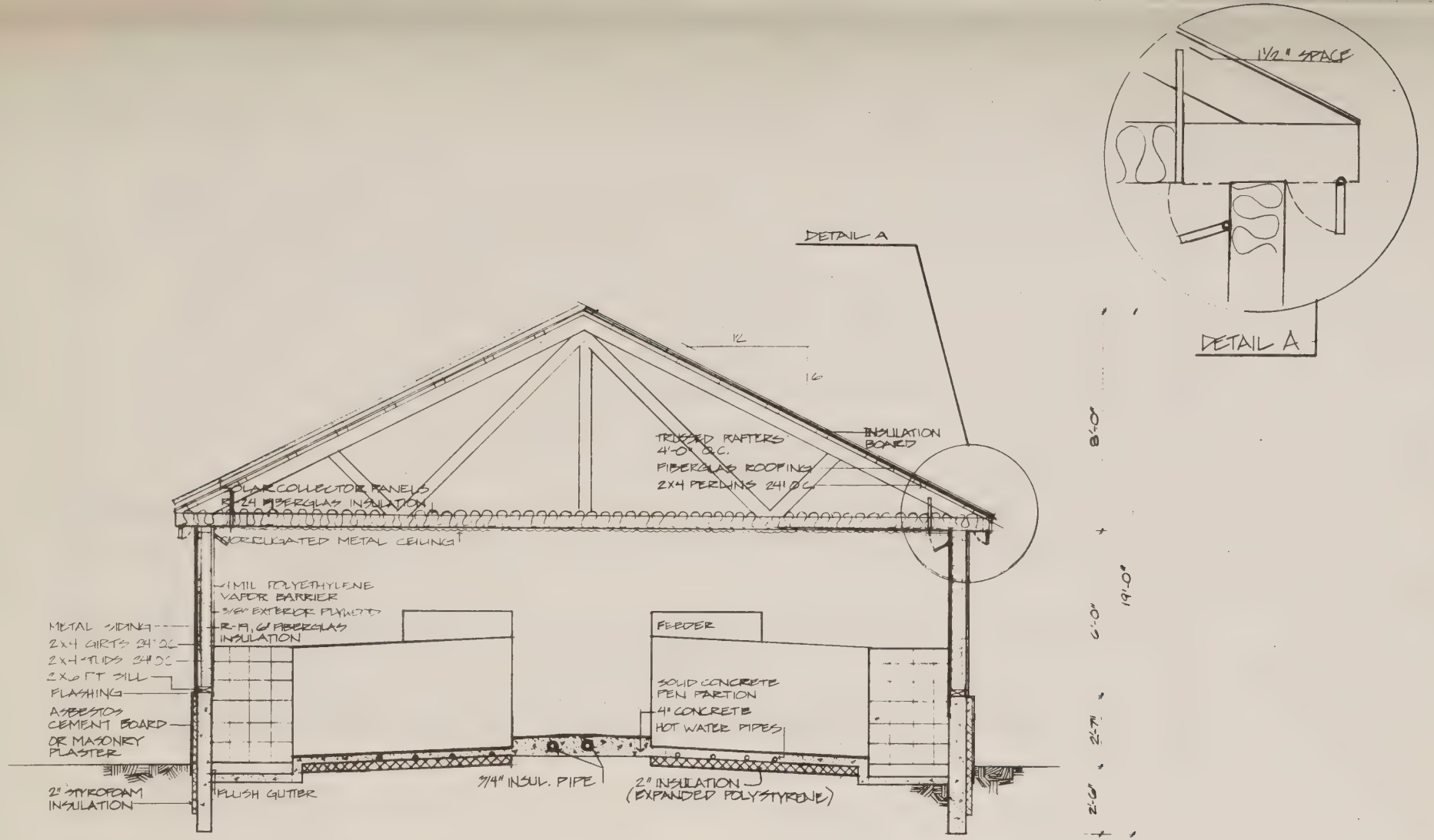




(SEE PAGE 3.)

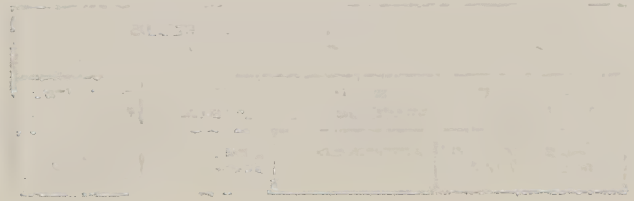


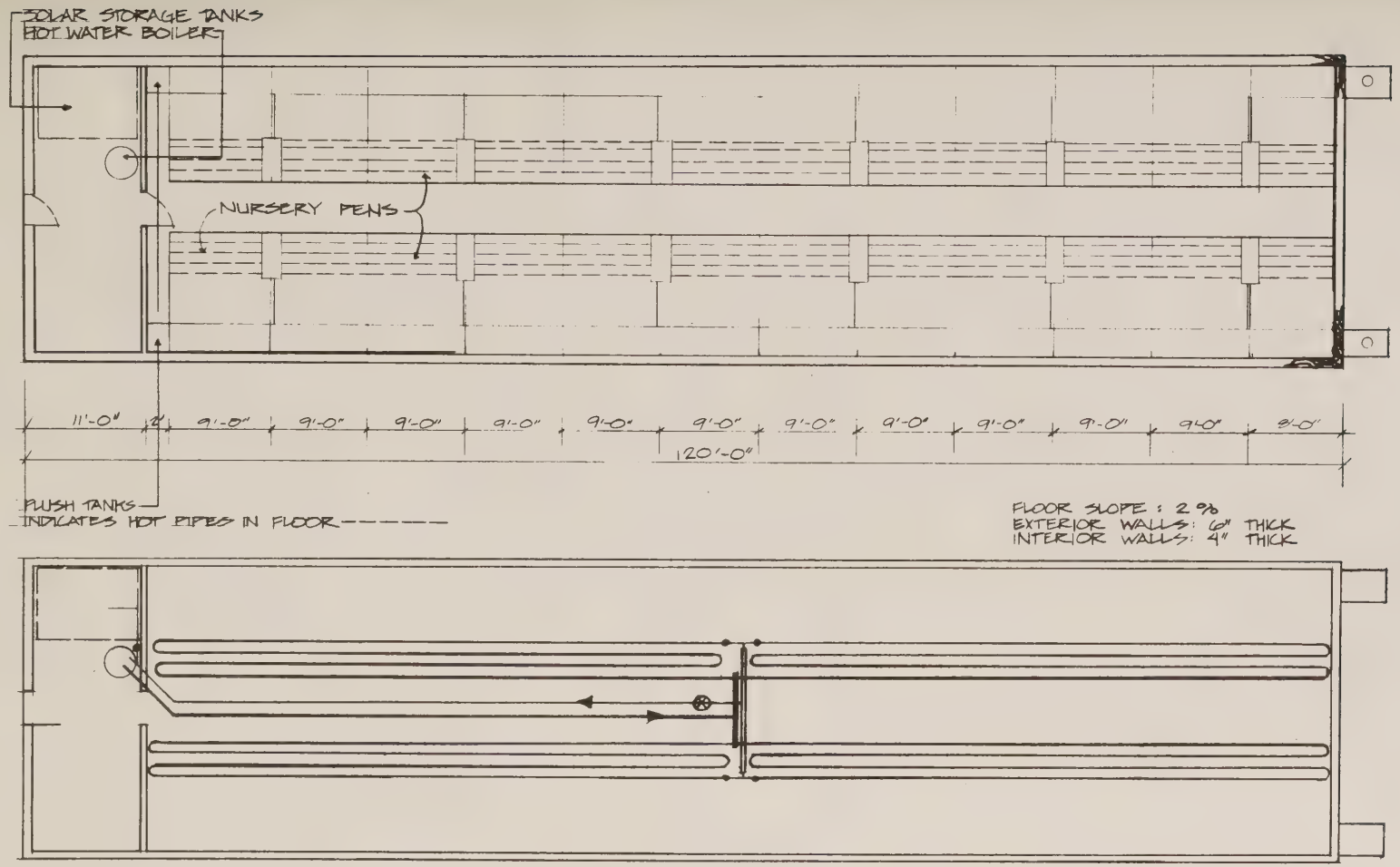
SOLAR DEMONSTRATION PROJECT POGUE NURSERY BUILDING			
AGRICULTURAL ENGINEERING DEPT. UNIVERSITY OF MISSOURI—COLUMBIA			DRW // PRJ 3
SCALE: NONE DATE: 7/1/79	APPROVED BY:	DRAWN BY: VEK	SHEET: 1 OF 3



SOLAR DEMONSTRATION PROJECT
POGUE - CROSS SECTION: NURSERY

AGRICULTURAL ENGINEERING DEPT. UNIVERSITY OF MISSOURI - COLUMBIA			DRW. / PRJ. 13
SCALE: 3/8"=1'-0" DATE: 7/11/79	APPROVED:	DRAWN: VRK	SHEET: 2 OF 3





SOLAR DEMONSTRATION PROJECT FOGUE NURSERY BUILDING			
AGRICULTURAL ENGINEERING DEPTARTMENT UNIVERSITY OF MISSOURI - COLUMBIA			DRW. PRJ. 3
SCALE: 1/8"-0" DATE: 9/05/79	APPROVED:	DRAWN: LEK	SHEET 3 OF 3

V. Performance data on the system were collected during March-April and November-December 1981. Results obtained are summarized below.

Performance Data - Pogue System

	1981	
	March-April	November-December
Incident Radiation (Btu/ft^2-day)	2,450	960
Collected Energy (Btu/day)	333,600	72,000
Collector Efficiency	.28	.16
Average Outside Temperature (^oF)	53	37
Value of Collected Energy ($/day)	2.74	.60

The water collection system performed without incident until failure of the boiler due to deposits of water dissolved mineral after 18 months of operation. This failure was the result of abnormally hard water (250 + ppm) and the relatively large volume of water in the storage-heating coil system.

During the March-April period, the solar system provided energy equivalent to about 4.5 gallons of propane per day. The Winter of 81-82 was a poor solar winter in Missouri and the lowered system efficiency reflects this. Energy saved during November-December approximated 1 gallon of propane per day. The solar system supplied essentially all of the supplemental energy required by the floor heating unit during the April-September period.

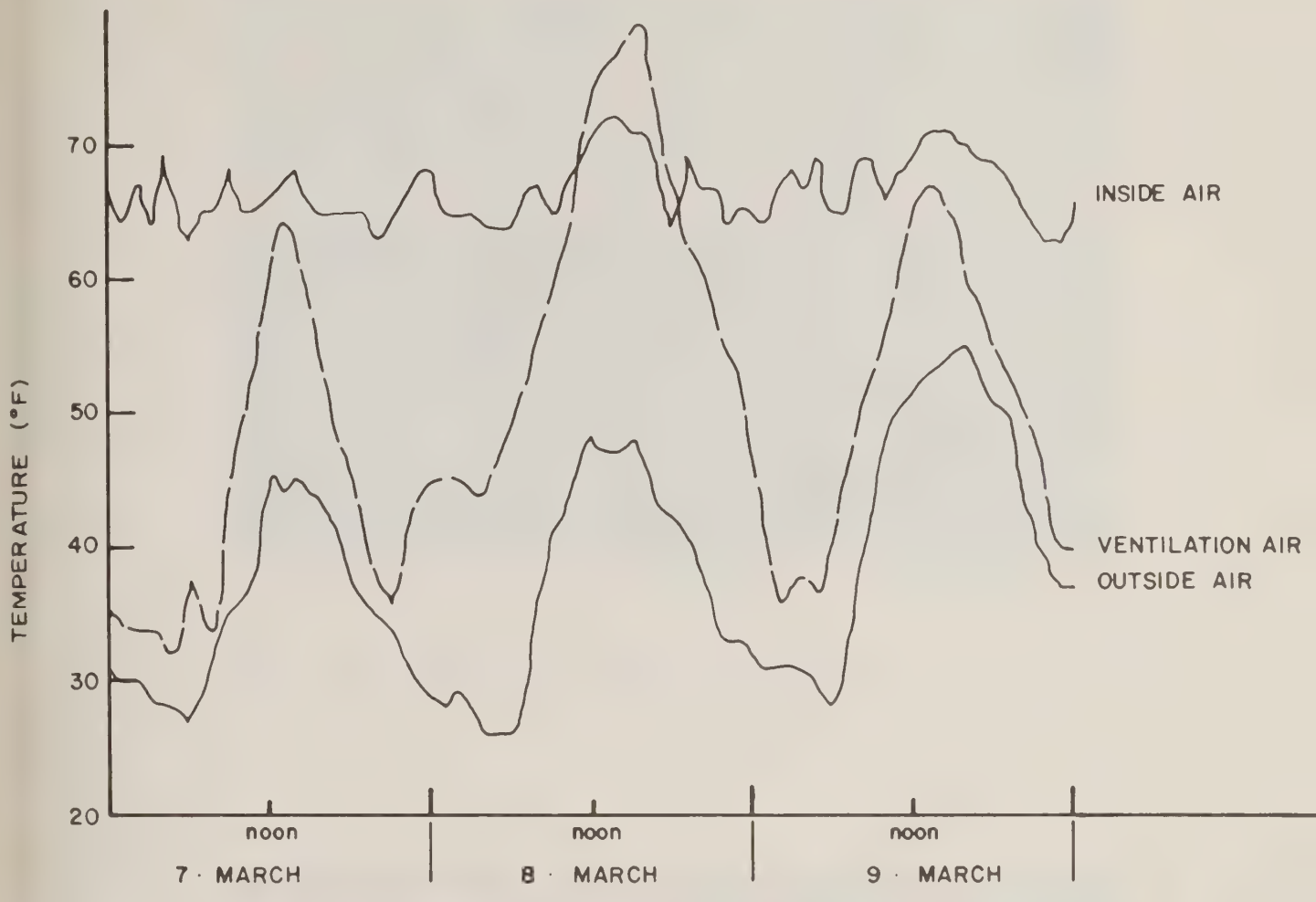
Ventilation air taken through the solar attic during winter months was preheated by an average of 10.8 degrees at solar noon. Efficiency of the solar attic ventilation preheat portion of the system could not be evaluated because of difficulty in measuring air flows through the variable speed fan units. Typical performance data are illustrated.

It can be seen from these data that routing incoming ventilation air through the attic was effective in capturing heat lost through the ceiling area during periods of no sun (night hours).

The water collector was unable at any time to sustain the 40 percent efficiency which had initially been projected for it. It appears that a value of 20-25 percent would be a reasonable estimate for efficiency of a system of this type.

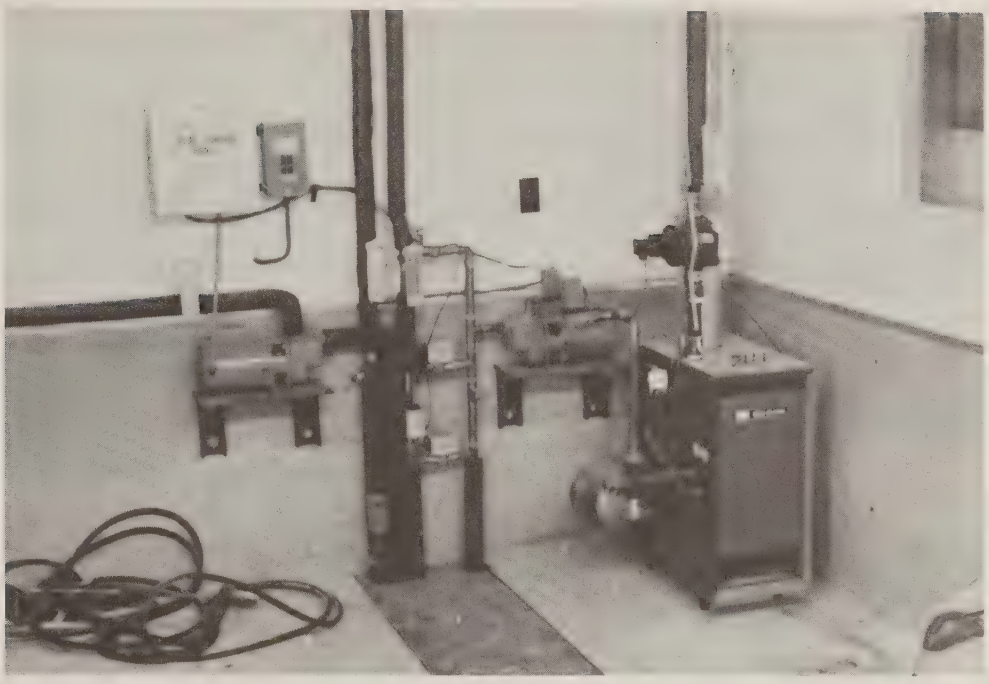
This range is consistent with results from 3 other systems of this type which we have been working with.

DATA FOR POGUE NURSERY - 1981





Exterior view of the Pogue nursery showing the South facing collector surface.



Interior view of the solar control panel and circulating pump. The supplemental boiler is located at the right. The hot water storage tank is below the floor.



Failure of the boiler unit resulted from deposition of minerals contained in water from the storage tank. After repair of the boiler, the storage was refilled with softened water.

FARM NO. 4

I. Alan Adam, Route 2, Vandalia, Missouri, is a partner in a large swine production operation currently producing about 5,000 market sized hogs per year. The farm and the solar demonstration building are located in the East Central part of Missouri.

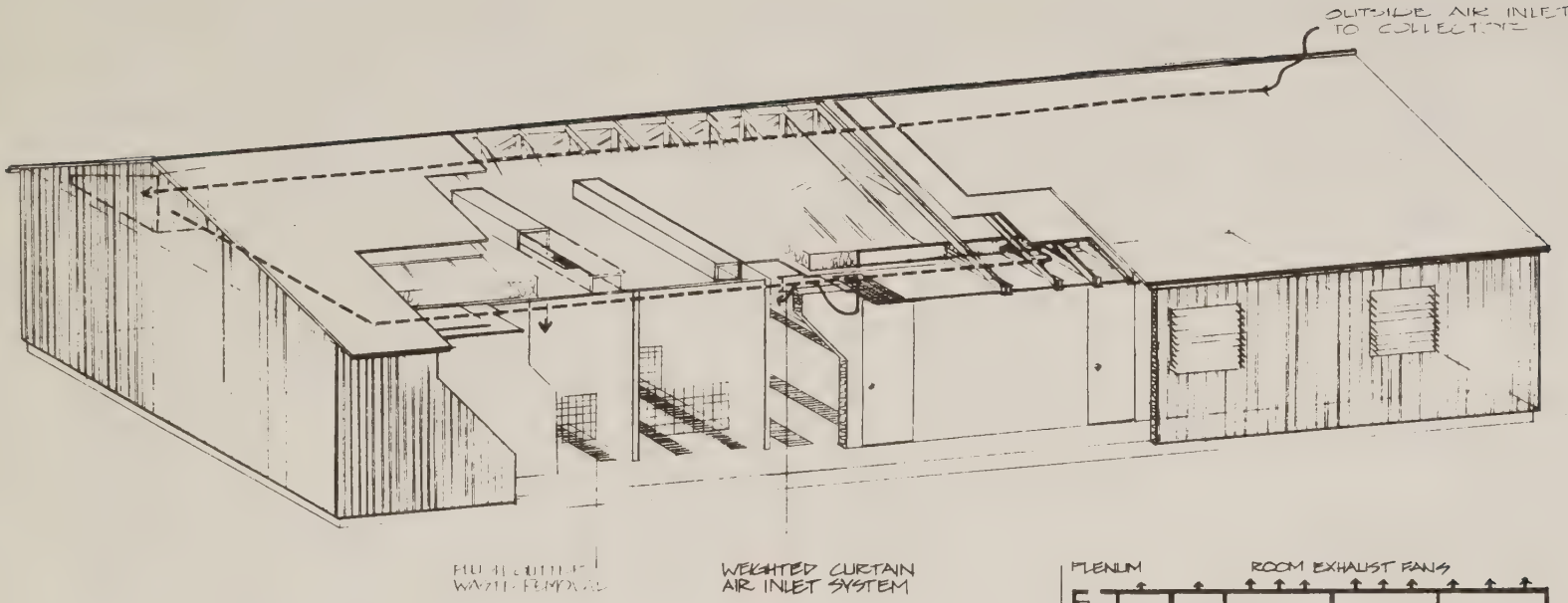
II. The objective of this solar system was to provide preheating for ventilation air.

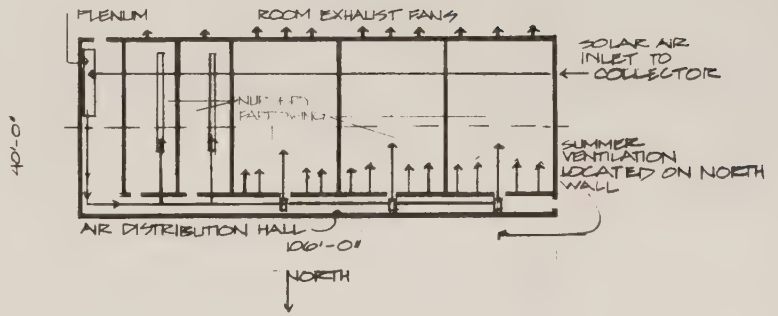
III. The solar collector was incorporated into the South slope of the roof on a new 40' x 106' combination farrowing-nursery building. System design was done by the manufacturer supplying the building (Bonanza Buildings, Inc.).

Roof purlins on the South slope were covered with a black painted composition board. The upper half of the South roof was covered with fiberglass reinforced plastic spaced 1 1/2 inches above the absorber. The lower half of the roof was covered with dark colored metal, also spaced 1 1/2 inches above the absorber.

Air enters the space between the roof covering and the absorber at the West end of the structure. It is drawn the length of the building and then into a hallway running along the North wall. The hallway serves as an inlet plenum for the ventilation air which is drawn into the individual farrowing and nursery rooms.

IV. The system was completed and placed into operation in late Fall of 1979. The solar option added $6,136.73 to the cost of the building or $3.06 per square foot of collector. Subsequent to completion of the demonstration unit, Mr. Adam doubled the size of the building and constructed a second solar collector.





SOLAR DEMONSTRATION PROJECT ADAM · FARROWING NURSERY BUILDING			
AGRICULTURAL ENGINEERING DEPARTMENT UNIVERSITY OF MISSOURI - COLUMBIA			DWG/PRJ 4
SCALE: DATE: 7/18/79	APPROVED:	DRAWN: LRK	SHEET 1 OF 1

V. Data were collected on the system during 3 periods; February 1980, February-March 1981, and February-March 1982. A summary of results obtained during these periods is listed below:

Adam Building

	February 1980	February-March 1981	February-March 1982
Solar Radiation Average Btu/ft^2-day	1340	1585	1526
Heat Added to Ventilation Air 1000 Btu/day	213	329	267
System Efficiency	.08	.10	.09
Average Outside Temperature	27	44	38
Average Inside Temperature	63	73	76

The fact that this facility has no heat storage results in some of the solar energy being wasted (peak solar pick up usually coincides with peak outside temperatures and minimum heat demand). This is particularly true during spring and fall months when diurnal highs often exceed desired inside temperature.

The unneeded solar energy added to the building does result in higher than normal ventilation rates during a portion of the day. These higher rates help remove excess moisture from the structure and materially reduce interior odor levels. The owner feels this is a very positive, although not quantifiable, feature of the solar system.

Based on an average system efficiency of approximately 9 percent this solar unit could be expected to add about 180 million Btu to the building during the October-March period. If 40% of this heat is effectively utilized, it would represent a savings of about $600 per year

in space heating costs for the unit. This would result in a simple pay back period of slightly over 10 years.

Three major problems contributed to the relatively poor performance of this system.

1. Failure of the contractor to carefully seal all of the construction joints led to the introduction of cold outside air into the system, greatly eroding performance.
2. The designed use of the attic space as a warm air supply plenum to the North hallway contributed to the air leakage problem and allowed for temperature stratification. It was not unusual to find a temperature variation of 15 degrees or more between the attic floor and the peak of the building.
3. The entire South slope of the roof should have been covered with fiberglass reinforced plastic. Apparently the designer felt that this would result in too much energy collection.

In addition to the above problems, the black composition board is deteriorating with time, leading to additional system leakage.

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floor and the peak of the building.

3. The entire south slope of the roof should have been
covered with fiberglass reinforced plastic. Apparently
the designer felt that this would result in too much
energy collection

4. In addition to the above problems, the black composition board
deteriorating with time, leading to additional system leakage.

FARM NO. 5

I. Veldron Hannah, Route 2, Bolckow, Missouri, operates a 560 acre crop and livestock farm in Northwest Missouri. His swine enterprise produces approximately 650 market hogs per year.

II. The solar system at this site was constructed as a part of a new farrowing-nursery building. Design objectives included:

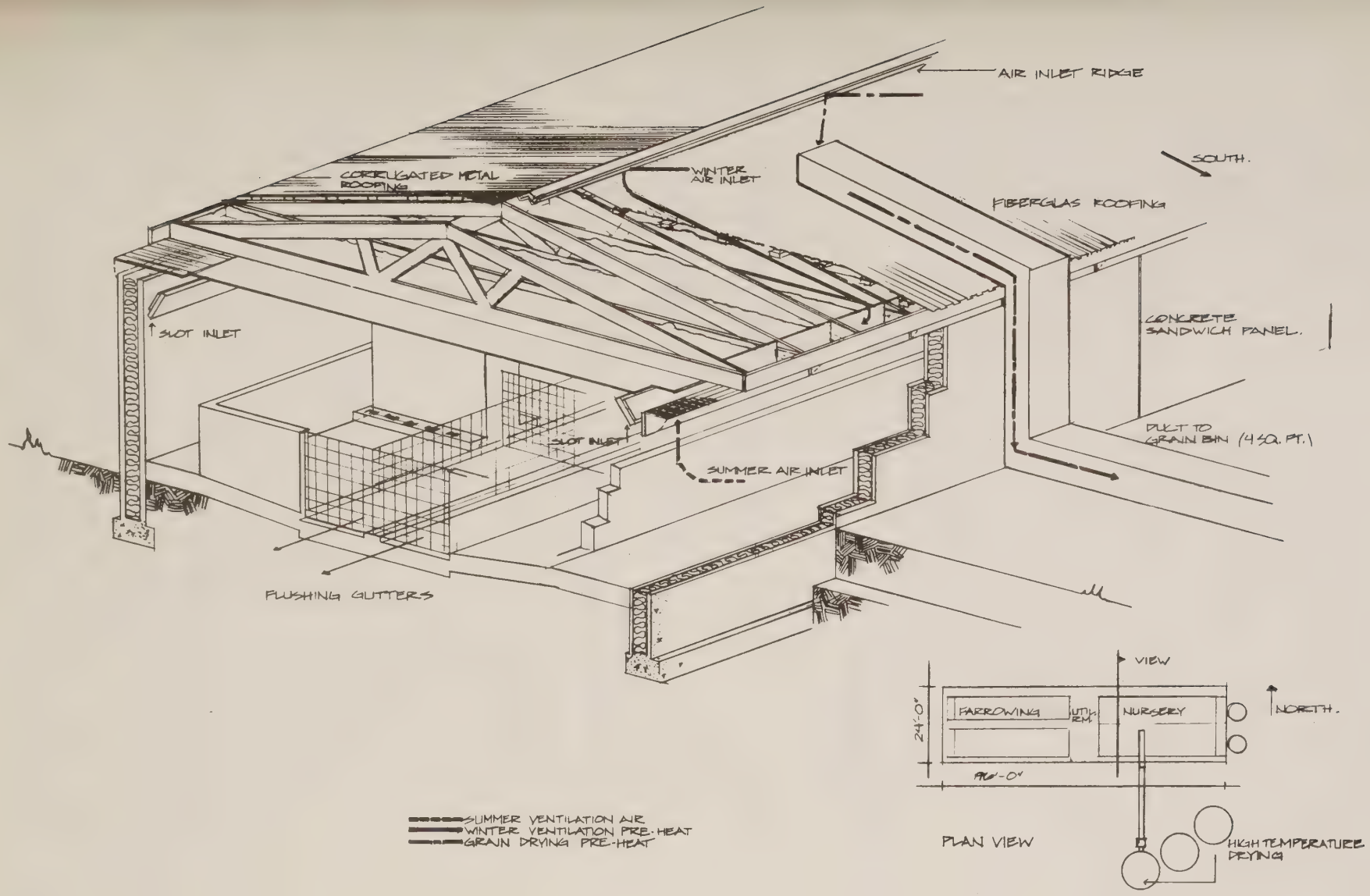
1. Preheating of ventilation air for the swine facility during winter months.
2. Preheating of inlet air for a nearby grain drying unit during the early fall.

III. A 24' x 100' tilt up concrete sandwich panel building was constructed with a central office-storage area. The East end of the building contains a nursery area and the West end is equipped with 20 farrowing crates. Ridge orientation is E-W.

The entire South slope of the roof was covered with fiberglass reinforced plastic instead of the normally used metal roofing. During winter months, ventilation air is admitted to the solar heated attic through a continuous ridge ventilator. It then passes into the animal housing area through a continuous slot inlet along the South edge of the ceiling. During summer months, drop down doors in the soffit are opened, allowing ventilation air to be taken directly from outside the building.

A 4 square foot duct connects the solar attic to the adjacent grain dryer. When the dryer is in operation, a portion of the air supply (approximately 3,000 cfm) is drawn directly from the attic.

IV. The building and solar attic were completed in 1979 and the connecting duct to the grain dryer in November 1980. Added cost for the solar unit totaled $1,821.00 or approximately $1.40 per square foot of collector.



SOLAR DEMONSTRATION PROJECT HANNAH FARROWING/NURSERY/GRAIN DRYING			
AGRICULTURAL ENGINEERING DEPARTMENT UNIVERSITY OF MISSOURI – COLUMBIA			DRW./PRJ. 8
SCALE: NONE DATE: 7/10/79	APPROVED BY:	DRAWN BY: LRK.	SHEET: 1 OF 1

V. The ventilation preheat system was instrumented and monitored in November-December 1980. Failure in the recording system resulted in a loss of solar insulation data for the period. During the monitoring period, the preheat system increased incoming ventilation air temperature 12-14 degrees above outside air temperature during periods of maximum sunshine.

The grain drying preheat portion of the system was instrumented for the fall drying season in 1981. Following is a summary of the data collected.

Hannah Grain Drying

	September-October 1981
Total Hours Operated	130
Average Temperature Rise Through Collector	2.66 ^{o}F
Average Temperature Rise Through Burner	89 ^{o}F
Solar Radiation During Operating Hours	9,520,000 Btu
Energy Added to Air By Collector	786,515
Energy Added by Heater	26,315,000
Proportion of Energy Supplied By Solar	.03
Value of Solar Energy Supplied	6.46
Collector Efficiency	.08

It appears that some outside air is being drawn directly into the ventilation system without going through the solar attic. Temperatures in the attic ranged as much as 30 degrees above outside while inlet air was 12-14 degrees above outside.

In reviewing performance of this system and the system at the Alan Adam farm, it appears questionable if designs utilizing the entire roof as a collector can be adequately utilized in relatively low volume air heating without extensive training of contractors and builders involved in their construction.

In examining records of the grain dryer operation, it appears that some changes in management might have increased the solar proportion of the total fuel used. In many cases, the system was operated for only a few hours per day; often during periods of low solar energy.

This system was one of the least expensive of all the units in the Missouri project. However, payback is still questionable in view of the extremely low efficiencies obtained.

FARM NO. 6

I. Gerald Sandidge operates a large swine farm at Marshall, Missouri. Annual production is nearly 17,000 market hogs. In addition, the farm also supports a large row crop production enterprise and a cattle herd.

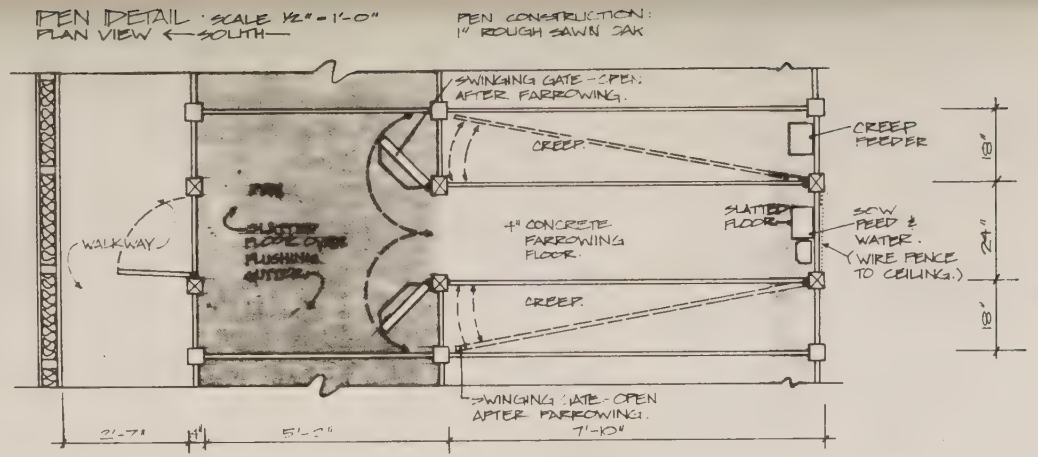
II. The solar demonstration unit on this farm was integrated into the construction of a new 60 sow capacity farrowing building. Project objectives included the following:

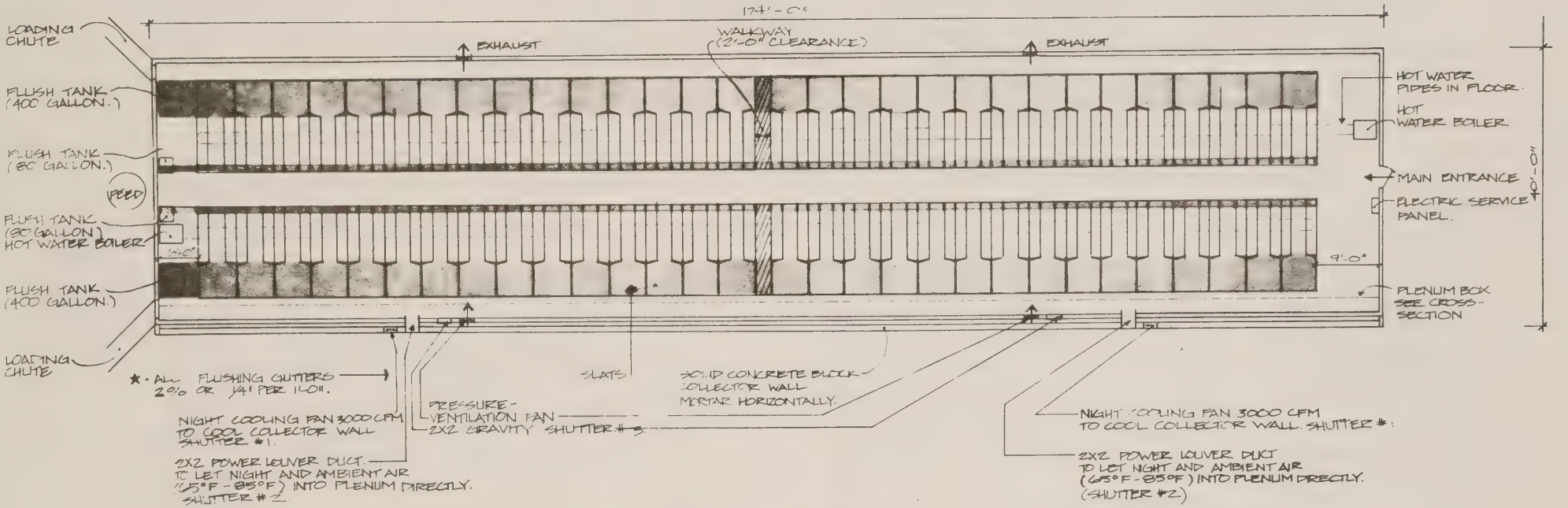
1. Provide ventilation air preheating with solar heat storage during the colder portions of the year.
2. Investigate the effectiveness of a reflector in enhancing the collection of solar energy.
3. Utilize the heat storage unit in a summer cooling mode to moderate high temperatures.

III. The principal structure is a 40' x 174', frame construction, clear span, insulated building with two rows of farrowing pens. Ridge orientation is East-West and the entire South wall was fitted with a K-State type collector-storage unit.

Two fan-shutter systems were installed in the wall for the purpose of drawing cool night air through the storage during summer months. White hinged plywood panels were attached to the base of the wall. These fold down during winter to reflect solar energy into the collector. In summer, the panels completely cover the solar wall to minimize any solar heat gain.

IV. The unit was completed in July 1980 at a cost of $18,363.00 or $13.19 per square foot of collector.



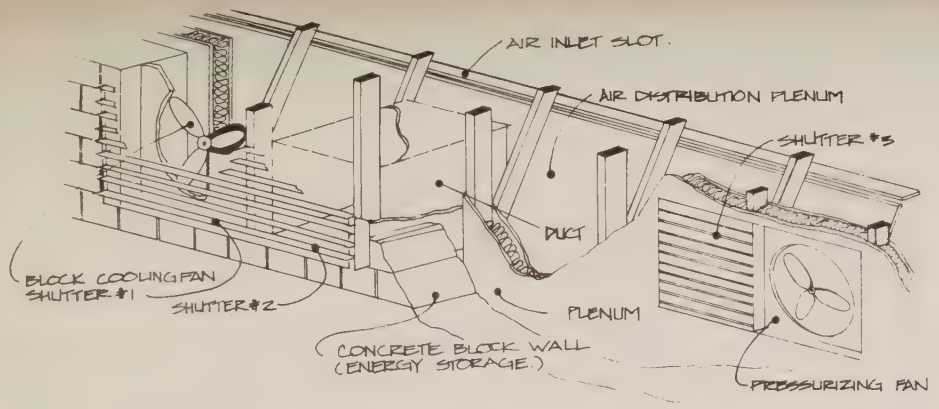


FLOOR PLAN · SCALE 3/32" = 1'-0"



SOLAR DEMONSTRATION PROJECT
SANDIDGE FLOOR PLAN

AGRICULTURAL ENGINEERING DEPT. UNIVERSITY OF MISSOURI-COLUMBIA			DWG. PRJ. 38-726-C2
DATE: 4-28-80 SCALE: ABOVE	APPROVED: REP	DRAWN: LRK	SHEET: 1 OF 2



OPERATION

WINTER OPERATION:
1. BLOCK COOLING FAN - OFF
2. PRESSURIZING FAN DELIVERING MINIMUM VENTILATION RATE - ON
3. SHUTTERS 1 & 2 - CLOSED.

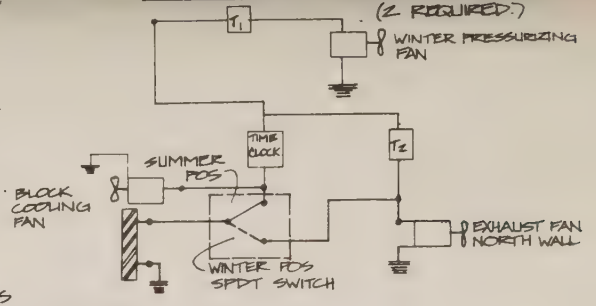
SPRING & FALL OPERATION
1. BLOCK COOLING FAN - OFF
2. PRESSURIZING FAN - ON
3. VENT FANS NORTH WALL OPERATE ON THERMOSTAT DEMAND.
4. SHUTTER 2 OPENS WHEN NORTH VENT FANS ON.

SUMMER OPERATION
DAY
1. BLOCK COOLING FAN - OFF.
2. PRESSURIZING FAN - ON.
3. VENT FANS (NORTH WALL) - ON.
4. SHUTTER 3 OPENS BY STATIC PRESS
5. SHUTTER 2 - CLOSED.

SUMMER OPERATION
NIGHT
1. BLOCK COOLING FAN - ON
2. PRESSURIZING FAN - OFF
3. VENTILATING FAN NORTH WALL - ON
4. SHUTTER 2 - OPEN
5. SHUTTER 3 - CLOSED GRAVITY.

★ NOTE: INSTALL GABLE END VENTILATION. 1.5 SQ. FT / 100 SQ. FT OF BLDG.

FAN-SHUTTER CONTROL SCHEMATIC



SHUTTER #2 POWER OPERATED (NORMALLY CLOSED)

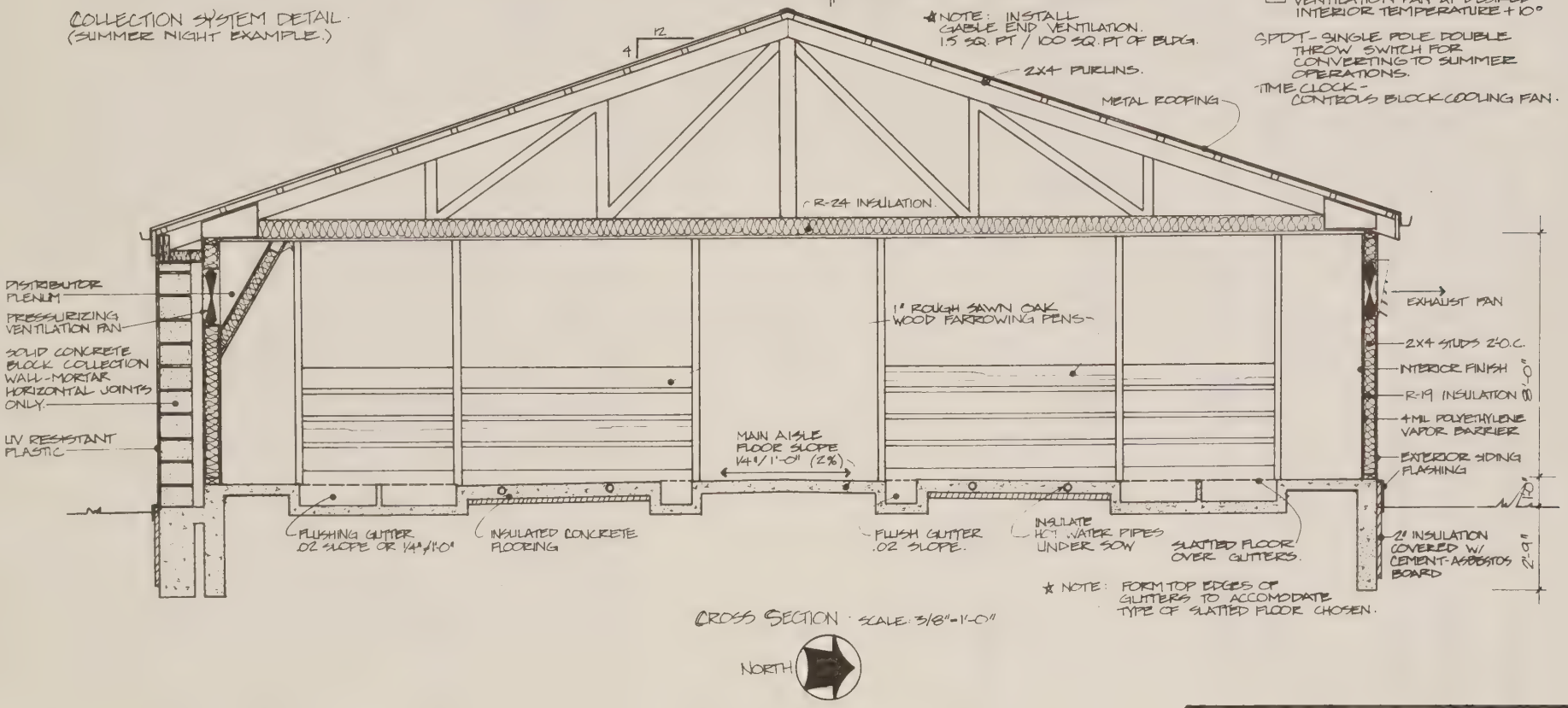
T1 - THERMOSTAT SET TO TURN OFF PRESSURIZING FAN AT DESIRED INTERIOR TEMPERATURE + 10°

T2 - THERMOSTAT TO TURN ON VENTILATION FAN AT DESIRED INTERIOR TEMPERATURE + 10°

SPDT - SINGLE POLE DOUBLE THROW SWITCH FOR CONVERTING TO SUMMER OPERATIONS.

TIME CLOCK - CONTROLS BLOCK COOLING FAN.

COLLECTION SYSTEM DETAIL (SUMMER NIGHT EXAMPLE.)

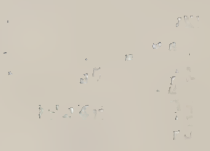


★ NOTE: FORM TOP EDGES OF GUTTERS TO ACCOMODATE TYPE OF SLATTED FLOOR CHOSEN.

CROSS SECTION · SCALE: 3/8"=1'-0"

NORTH

SOLAR DEMONSTRATION PROJECT SWINE CROSS SECTION			
AGRICULTURAL ENGINEERING DEPT. UNIVERSITY OF MISSOURI COLUMBIA.			DRW. PRJ. 33-726-C2
DATE: 4-28-80 SCALE: 3/8" = 1'-0"	APPROVED: REP	DRAWN: JRK	SHEET: 2 OF 2



V. The summer cooling mode was placed into operation immediately upon completion of the unit. It was able to maintain satisfactory temperature levels within the building up to the point when outside temperatures exceeded 100°F. Temperature depression of 15 degrees was regularly achieved with the system.

Performance data were collected for the heating mode during January-February 1981 and for the cooling mode during July 1981. Following are summaries of these data.

Heating Mode-Sandidge Building

	January-February 1981
Solar Radiation Average Btu/ft^2-day	1275
Heat Added to Ventilation Air 1000 Btu/day	948
System Efficiency	.53
Average Outside Temperature (°F)	31
Average Inside Temperature (°F)	73

Cooling Mode-Sandidge Building

		July 1981
Average Outside Temperature (°F)		83.8
Average Inside Temperature (°F)		81.1
Average Daily Maximum	Outside	97.2
	Inside	89.1
Average Daily Minimum	Outside	72.7
	Inside	77.1

The solar system added energy equivalent to 12.6 gallons of LP per day to the building during January-February 1981. On a year round operational basis, it appears that the system will save approximately 2000 gallons of LP gas per year valued at $1,200.00. This results in a simple payback period of slightly over 9 years for the heating portion of the system. No attempt was made to evaluate energy cost savings for the cooling mode because of difficulty in quantifying output.

The only problems with the system to date occurred in the cooling mode during the Summer of 1981. Average relative humidities during July were very high (frequently above 75%) and the "sensible only" cooling achieved with the system resulted in saturated cool air being introduced to the building. This created a considerable amount of undesirable condensation and required that the system be operated to bring in greater than normal amounts of ventilating air directly from outside.

This unit is very well constructed and no recommendations for change appear necessary at the present time.



This solar collector owned by Gerald Sandidge has provisions for Summer cooling using the heat storage wall. The fold down panels cover the collector during Summer months and act as a solar intensifier during the Winter.

FARM NO. 7

I. Gale Snow owns and operates an 80 cow dairy farm near Wheatland in Southwest Missouri. Milking is done in a concrete block construction milking center with minimal insulation.

II. Major energy requirements associated with the milking operation are for heating of water used in cow washing and equipment clean up. A lesser amount of energy is required to maintain milk center temperatures above freezing.

Project objectives are as follows:

1. Preheat water used for cow washing and equipment clean up.
2. Demonstrate feasibility of using commercial water based collector system.
3. Provide heat for freeze protection in the milking center.
4. Integrate solar heat collection with a system to recover energy removed from milk in the refrigeration process.

III. Design calculations included the following analysis of energy needs for the unit.

Assumptions:

1. Preheat of cold water from 50^{o} up to 100^{o}F. Additional heat required for equipment wash will be provided by gas fired heaters.
2. Space heat for freeze protection only.

Month	DAILY ENERGY REQUIREMENTS IN BTU		
	Water Preheat	Space Heat	Total
		1000 BTU	
Nov.	72.6	202	275
Dec.	72.6	574	647
Jan.	72.6	709	781
Feb.	72.6	573	646
Mar.	72.6	270	343

3. Energy available from cooling milk:

   80 cows x 34 lbs x 60^{o} = 163,000 Btu

4. A 120 square foot collector operating at 40% efficiency in combination with the heat recovered from the milk would supply the following estimated heat.

Month	Milk Heat (1000 Btu)	Solar Heat	% of Needs
Nov.	163	57	80
Dec.	163	54	33
Jan.	163	57	31
Feb.	163	66	35
Mar.	163	69	68

5. Storage design criteria -

   (a) 1/2 day collection from milk.

   (b) 1 day (January) solar input.

   (c) 50^{o} working range.

   Capacity required: 334 gallons.

   Recommendation based on tank availability: 1000 gallons.

A 1000 gallon precast concrete tank was buried in the ground adjacent to the milking center. The tank was insulated with 2" of polystyrene.

A 120 square foot commercially produced solar system (Sunduit Corporation) was installed on the milking center roof.

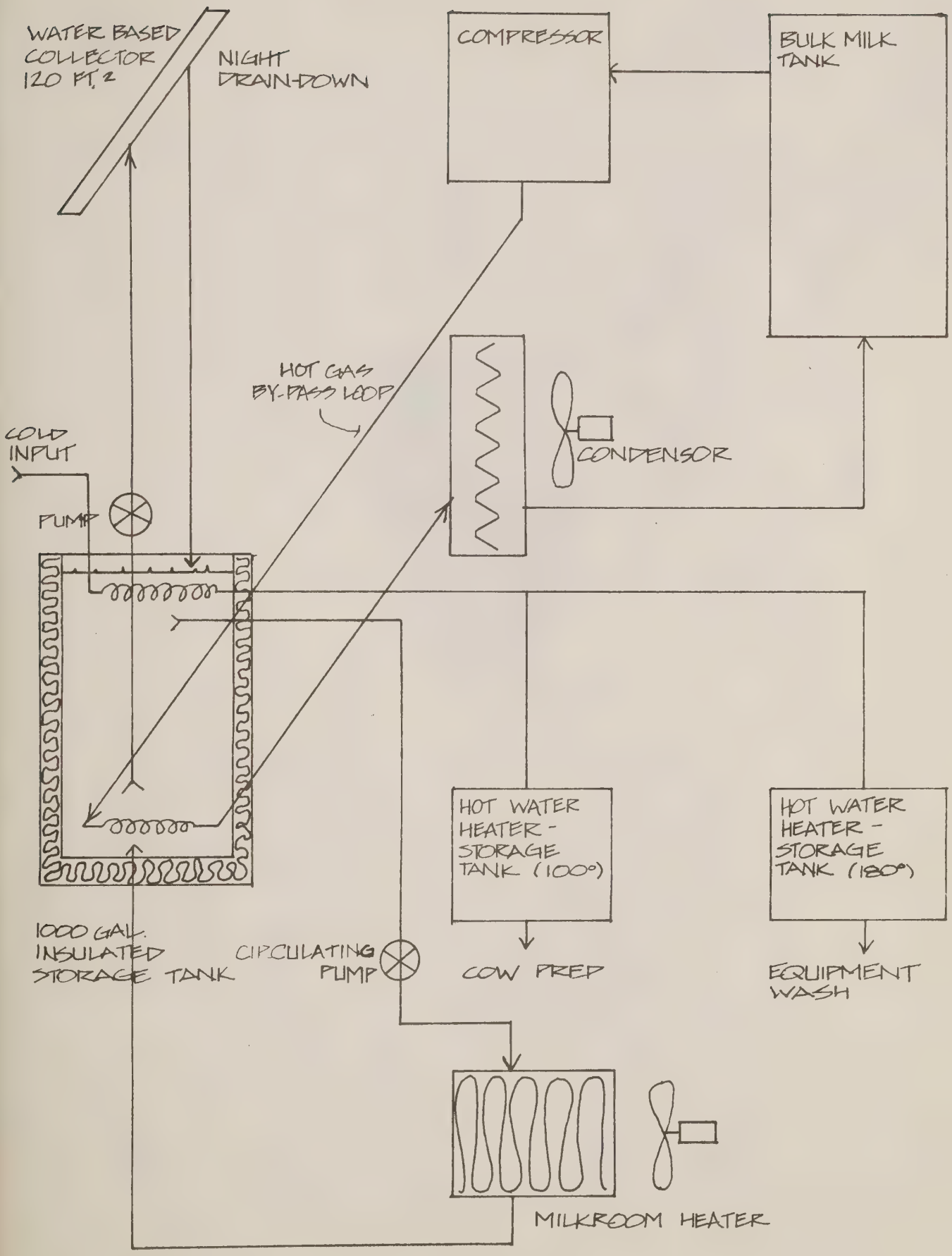
The hot gas line from the compressor was broken and a copper coil located in the storage tank was inserted in the line.

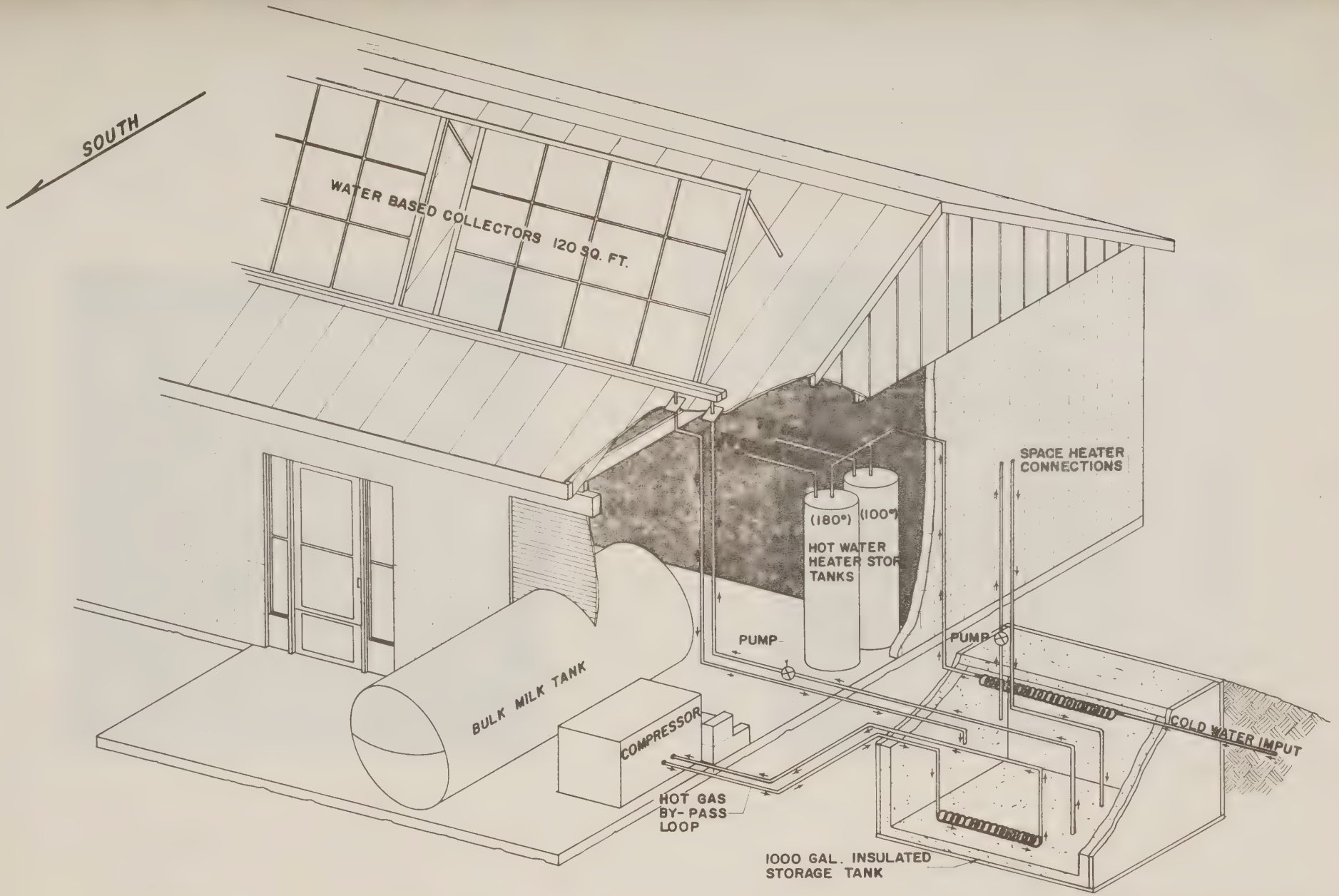
A copper coil, also located in the storage tank, was installed in the cold water supply line to serve as a heat exchanger. Two hot water heaters are supplied by this preheated coil. One unit set at 100° supplies water to the cow wash system. The other at 180° is used for equipment washing.

Fan forced hot water space heaters are supplied directly with water from the storage tank.

Water in the storage was treated with sodium borate to pH 11 to prevent microorganism growth.

IV. The system was completed in March 1980 at a cost of $5,539.51 or $46.15 per square foot of collector.


WATER BASED COLLECTOR 120 FT.²
NIGHT DRAIN-DOWN
COMPRESSOR
BULK MILK TANK
HOT GAS BY-PASS LOOP
COLD INPUT
CONDENSOR
PUMP
HOT WATER HEATER - STORAGE TANK (100°)
HOT WATER HEATER - STORAGE TANK (180°)
1000 GAL. INSULATED STORAGE TANK
CIRCULATING PUMP
COW PREP
EQUIPMENT WASH
MILKROOM HEATER



SOLAR DEMONSTRATION PROJECT
HOT WATER PREHEAT SYSTEM
- DAIRY -

UNIVERSITY OF MISSOURI
DEPT. OF AGRI. ENG.

DRWN. JR	DATE 1-26-81



Roof mounted collector preheats water used in the milking center for cow and equipment wash.



Close up view of the collector panel at the Gale Snow farm.

V. The system was instrumented for data collection during March-April 1980 and again in August 1981. A summary of data follows:

Water Heating-Gale Snow

	March-April 1980	August* 1981
Solar Radiation Btu/ft^2-day	1466	1796
Collected Energy Btu/day	37,000	102,000
Water Usage gal/day	277	178
Heat Added to Water Btu/day	869,000	28,560
Collector-Storage Efficiency	.21	.47
Storage-Distribution Efficiency	---	.28
Average Outside Air Temperature (^{o}F)	48	75

*Refrigerant heat exchanger removed from system.

Few problems were encountered during the construction phase of this project. During the Summer of 1980, the heat exchanger coil from the compressor line failed. This coil was removed from the system at the time of failure and it was operated as a solar only system from that point on.

It is apparent from the data that the major energy input was from the compressor coil. In fact, it appears that compressor heat recovery is a much more viable energy source for dairy farms than is the use of solar.

With an average system efficiency of approximately 15 percent, the solar system is expected to supply energy equivalent to 120 gallons of LP on an annual basis. At present fuel costs, amortization of the system would not be possible from fuel cost savings.

During the Winter of 1980-81, the drain down valve on the collector failed, resulting in failure of the absorber plate tubes. The system was repaired in the Summer of 1981 and the drain down valve relocated to a position inside the collector case.

Two differential thermostats have failed on this system.

It is obvious that high heat loss is occurring from the buried storage tank. Future systems should be constructed with higher insulation levels and with some means of positive water drainage around the tank.

Standard design practice (described in ASHRAE) was used in determining the size of the water heating coil. This resulted in a coil of inadequate size to achieve maximum heat gain. It appears that some type of storage agitation or a larger exchanger area will be required to achieve maximum heat pick up.

FARM NO. 8

I. Donald Martin operates a 120 cow, 400 acre dairy farm near Appleton City in Southwest Missouri.

II. The solar system demonstrated at the Martin farm is used for space heat in the milking center and to preheat hot water used in the milking operation.

III. The system design is essentially the same as that used on Farm No. 7 except that the cold water heat exchanger area was increased by using a metal tank in series with the copper exchanger coil.

IV. This system was completed in late Fall of 1980 at a cost of $5,707.00 or $47.55 per square foot of collector.

V. The drain down portion of this system failed during the 1980-81 Winter, resulting in failure of the absorber plate tubes. Tubes were replaced during the late Spring of 1981 and the system was converted to a closed loop system with anti freeze fluid and a coil type heat exchanger in the storage tank.

Failure of the refrigerant line also resulted in elimination of this portion of the system on this farm.

Water Heating-Donald Martin

	August 1981
Solar Radiation (Btu/ft^2-day)	1,777
Collected Energy (Btu/day)	64,300
Water Usage (gal/day)	170
Heat Added to Water (Btu/day)	19,200
Collector-Storage Efficiency	.30
Storage - Distribution Efficiency	.29
Average Outside Temperature (^{O}F)	75

Performance of this system was similar to that on the Snow farm except that collector to storage efficiency was 10-15 percent lower. This loss is attributed to the reduction in performance associated with the closed loop heat exchanger system as opposed to the drain down.

Installation of this system cannot be economically justified on the basis of total cost and expected energy savings.

FARM NO. 9

I. Freddie Martin owns and operates an 80 cow dairy farm near Humansville, Missouri.

II. The solar demonstration project at this site is intended to preheat water for space heating, cow washing and equipment clean up.

III. The overall system design is similar to that of Farm No. 8 with the following exceptions.

1. A 180 square foot collector was installed.
2. The refrigeration heat exchange loop was not installed.

IV. The system was completed in late 1980 at a cost of $4,770.00 or $26.50 per square foot of collector.

V. Data collected during October 1981 are summarized below:

Water Heating-Freddie Martin

	October 1981
Solar Radiation (Btu/ft^2-day)	1,175
Collected Energy (Btu/day)	50,500
Water Usage (gal/day)	202
Energy Added to Water (Btu/day)	30,500
Collector - Storage Efficiency	.24
Storage - Distribution Efficiency	.60
Average Outside Temperature (^{o}F)	57

The higher storage to distribution efficiencies obtained with this system as compared to Farms 7 and 8 is attributed to better tank insulation and the fact that data represent a time of year when soil

moisture is at a minimum.

The only problem with this system has been the inability to satisfactorily balance the flow of water through the three collector panels. Future systems of this type will require some mechanism to insure equal flow to all panels in order to prevent stagnation within individual units.

FARM NO. 10

I. Leslie Prier of Newtonia, Missouri, is a contract producer of turkeys. His operation is presently set up to produce 8,000-10,000 market birds every 8-10 weeks.

II. Turkey brooding on this farm is done in a 40' x 250' steel framed building with minimal insulation. The main objectives of this project were as follows:

1. Provide ventilation air preheating for the brooding unit.
2. Demonstrate a system which can be easily retrofit to existing poultry brooding buildings.

III. Design procedure -

Calculated Building Heat Loss:		326,000 Btuh
Calculated Ventilation Heat Needs:		136,800 Btuh
Sensible Heat Production:		16,000 Btuh
Net Heat Loss per $^{o}\Delta T$	=	4,700
Expected Daily Needs for Supplemental Heat Based on Ti	=	80^{o}

Month	Million Btu/day
Oct.	2.5
Nov.	3.9
Dec.	4.9
Jan.	5.2
Feb.	4.9
Mar.	4.1

Assumptions:

1. Collector efficiency of 40%.
2. 2,000 square feet available.

Anticipated Collection of Solar Energy

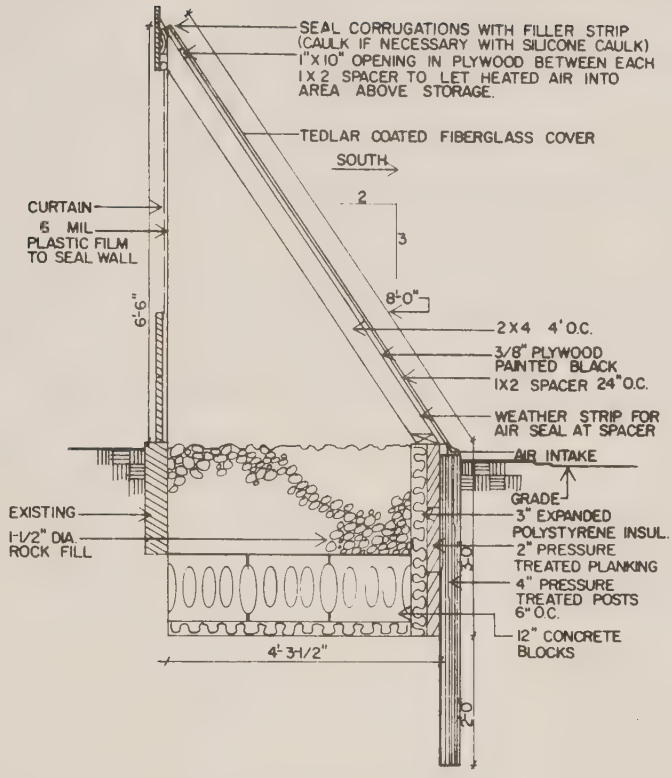
Month	Million Btu/day	% of Heat Required
Oct.	1.10	44
Nov.	.87	21
Dec.	.68	14
Jan.	.82	16
Feb.	.93	19
Mar.	1.06	26

System Description: A 3' deep x 4' wide trench was excavated adjacent to the south wall of the building. The trench was lined with insulation, a duct installed at the bottom, and was filled with 1 1/2" rock. A lean-to covered plate collector was constructed over the rock storage area.

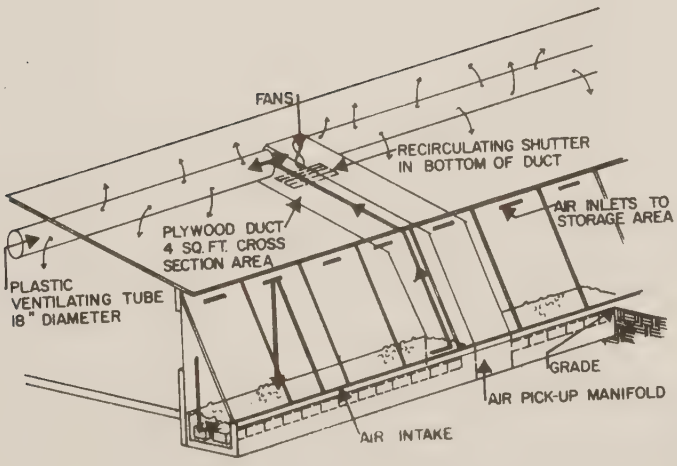
A collection plenum and duct at the center of the building provides air for the two pressure ventilation fans which distribute air to the building through perforated plastic tubes.

Design air flow was approximately 2 cfm per square foot of collector and there is approximately 1 cubic foot of rock storage per square foot of collector.

IV. The system was completed in November 1979 at a cost of $8,661.42 or $4.33 per square foot of collector area.



Section view of Prier system.



Pictorial illustrating air flow in Prier turkey building.

V. Data acquisition equipment was installed upon completion and data for November 17-December 31, 1979 indicated that the system was supplying energy equivalent to approximately 20 gallons of LP gas per day. The value of this energy was $12.00 per day.

The following observations are the result of over 2 years of system operation.

1. Essentially all of the solar energy captured appears to be offsetting purchased energy during winter months.
2. There have been some problems with the air handling system motors. These were not enclosed units as recommended.
3. Owner observation of performance in spring months has been extremely favorable. In one case, he was able to turn off the gas brooders completely at 3 weeks of age.
4. The owner was initially disappointed that the system had not decreased fuel costs. Upon examination of actual usage, it was found that his costs were nearly the same due to the increase in fuel price, despite the dramatic decrease in usage.

The changes in basic design and construction indicated below should help improve system performance.

1. Collector length should be limited to 100-125 feet.
2. A single fan should be used to pressurize the tube distribution system.
3. Air inlet to the collector should be at the top to minimize snow interference.

A summary of data collected during three different test periods follows:

Poultry Brooding Ventilation Preheat-Prier Farm

	December 1979	July 1980	January 1981
Incident Solar Radiation Btu/ft^2-day	1300	1800	1600
Heat Added to Ventilation Air 1000 Btu/day	1500	1300	2100
System Efficiency	.57	.35	.66
Average Outside Temperature	41	84	34

LP gas usage records kept by Mr. Prier indicated the following usage -

November-February 1977-78	46 gallons/day
November-February 1978-79	60 gallons/day
November-February 1979-80	30* gallons/day

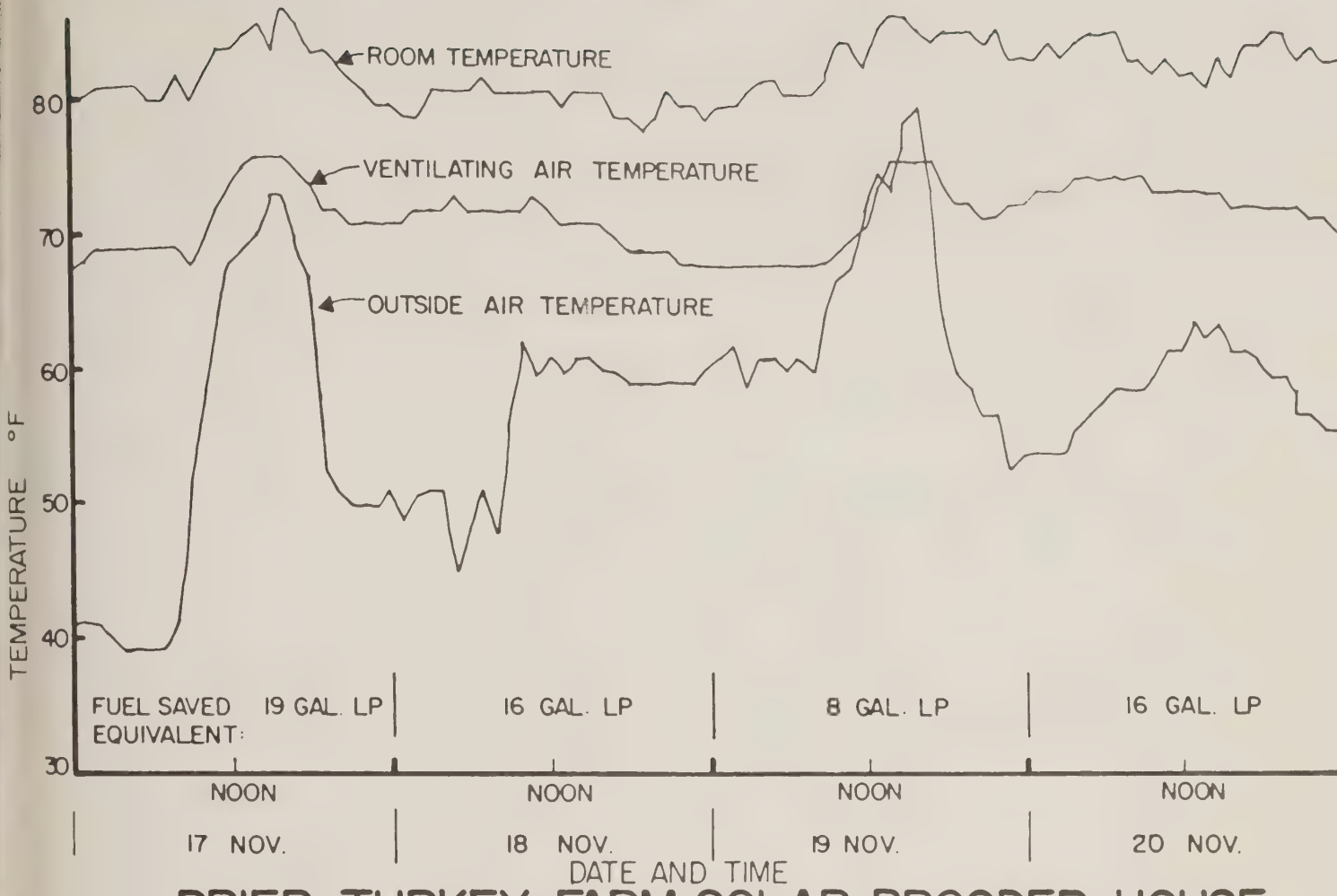
*With solar preheating system in operation.

The high heat demand on a year round basis for this unit contributes greatly to the effectiveness of the solar unit. Estimated payback period is 4-5 years.

As a result of our experiences with this system, we offer the following suggestions for constructing or modifying a collector-storage unit of this type:

1. Provide a single fan for the system or install fans with a baffle to prevent interference with each other.

2. Limit air flow lengths to 96-122 feet. This will allow for smaller ducts, less static pressure and improve system performance.
3. Distribution tubes for heated air need to be of equal length to insure proper tube inflation and temperature distribution.
4. By adequately insulating and sealing the South wall of the building, the plywood absorber could be eliminated from the system.



PRIER TURKEY FARM SOLAR BROODER HOUSE



Exterior view of collector unit on South wall of Prier building.

FARM NO 11

I. C. M. Price, Stark City, Missouri, operates a turkey brooding and growing operation similar to that on Farm No. 10.

II. Objectives of this demonstration project include the following:

1. Provide a minimum cost solar system to preheat ventilation air.
2. Test performance of a system without heat storage.
3. Reduce heat loss through the roof area of the building.

III. The existing 40' x 250' steel framed brooding unit is oriented North-South. The net heat loss per degree temperature difference was calculated at 4,700 Btuh.

Design criteria:

1. Provide 60% of the heat needed during daylight hours in January.
2. Collector efficiency of 40%.
3. Average daytime temperature 44^{o} F.
4. Average collection of 200 Btu/ft^2-day.

2" x 4" wood purlins were placed at 2' intervals over the center 125 feet of roof. This section of roof and the purlins were then painted black and covered with tedlar coated reinforced plastic sheets.

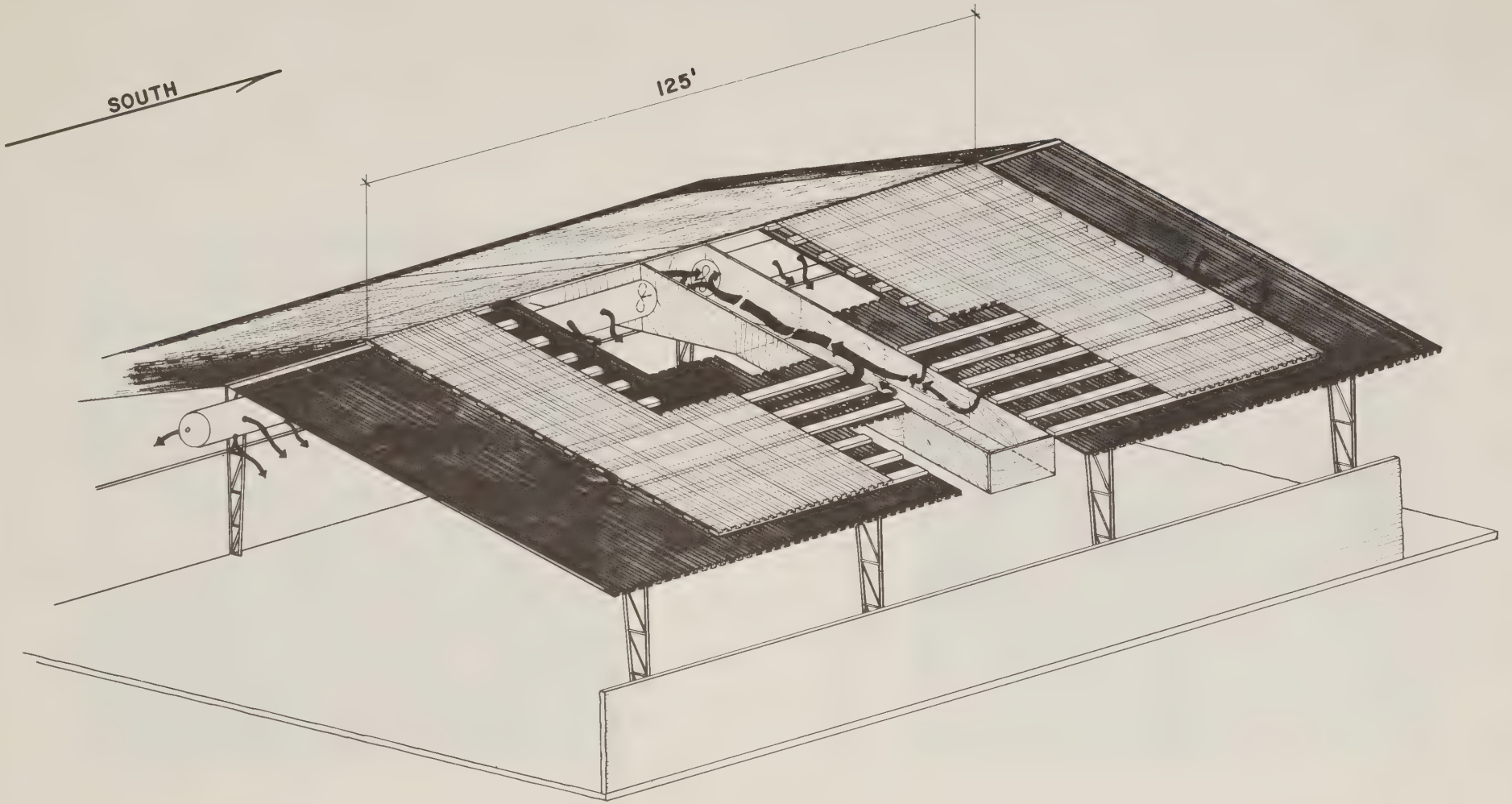
Air is drawn from both ends of the collector area to a center collecting duct located beneath the roof. It is then distributed through perforated plastic tubing at the center of the building.

IV. Construction was completed in April 1980 at a cost of $5,576.48 or approximately $1.11 per square foot of collector.

V. Data logging equipment was installed on this system during January 1981 and again in December 1981-January 1982. On both occasions, failure of component parts of the instrumentation resulted in an incomplete set of data.

The following conclusions can be drawn from the data available:

1. The design of the system is such that it is recovering a considerable amount of heat which escapes through the roof section during night time hours. The amount recovered is proportional to temperature difference between inside and outside. Average heat pick up is approximately 275 Btu per hour per degree temperature difference between inside and outside. This is approximately 50 percent of the calculated heat loss for the area covered by the collector. Assuming an average of 14 hours darkness for the December-February period and an inside temperature of 80^{o}, estimated recovery for the 3 month period of energy equivalent to 1000 gallons of LP gas.



SOLAR DEMONSTRATION PROJECT
AIR VENTILATION PREHEAT SYSTEM
C. M. PRICE

UNIVERSITY OF MISSOURI
DEPT. OF AGRI. ENG.

DRWN.	DATE
JR	1-30-81



View of the West roof slope showing solar collector unit in place. The East slope is similar.



Interior collecting duct and distribution tube used in Price system.

APPENDICES

APPENDIX A

The following University of Missouri Area Extension staff members were heavily involved with this project from its inception. Without their individual and collective help, there would have been no solar demonstration project in Missouri.

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APPENDIX B

Following is a partial listing of publications and other mass media materials developed as a direct result of this project.

1. Energy for Missouri Farms. UMC Guide 1970.
2. Active Solar Collectors for Farm Buildings. UMC Guide 1971.
3. Saving Energy With Passive Systems. UMC Guide 1972.
4. Model Solar System No. 1. UMC Guide 1973.
5. Model Solar System No. 2. UMC Guide 1974.
6. Sun Wraps Pigs in Warmth. Missouri Ruralist - June 1979.
7. 250 Ft. Collector Wall Can Save $12 + Daily in Fuel. Farm Building News - January 1981.
8. Solar Energy Works in Hog Houses, But - - -. Progressive Farmer - August 1981.
9. A New Kind of Earth Sheltered Barn. The New Farm Magazine - February 1981.
10. Solar Assisted Sow-Pig Nursery Unit. Proceedings of ILES 1981.
11. Solar Heated Earth Contact Pig Nursery. Proceedings of ILES 1981.
12. Solar Assisted Turkey Brooding System. Proceedings of ILES 1981.
13. Solar Heated Swine Nursery plan. UMC Agricultural Plan #32-726-C3.
14. Solar Assisted Farrowing House plan. UMC Agricultural Plan #33-726-C2.

SOLAR HEATING OF ON-FARM LIVESTOCK STRUCTURES

Demonstration Project

Final Report

Sponsored by:

Cooperative Extension Service
University of Nebraska-Lincoln

Department of Agricultural Engineering

with assistance from:

Department of Animal Science

Department of Agricultural Economics

in cooperation with:

United States Department of Agriculture

and

United States Department of Energy

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Solar Heating of On-Farm Livestock Structures

Demonstration Project

PROJECT OVERVIEW

This project was one of nine sponsored by the U.S. Department of Agriculture (U.S. Department of Energy pass-thru monies) to demonstrate the technical and economical potential of utilizing solar energy to reduce dependence on fossil fuels for operation of livestock production facilities. The University of Nebraska project was directed by faculty members in the Department of Agricultural Engineering having appointments with the Nebraska Cooperative Extension Service.

Cooperators were selected based on their willingness to work with the University of Nebraska. In each case the cooperator also had to be willing and able to make a financial commitment in a solar system the performance of which, for the most part, was unproven under commercial farm operation and management regimes.

The University of Nebraska, Cooperative Extension Service and Department of Agricultural Engineering are deeply indebted to each of the cooperators for his participation in this project. Although some difficulties and problems were encountered, overall the project must be considered a success. Only through unselfish sacrifices and risks by people such as the dedicated cooperators involved in this project can the University of Nebraska Cooperative Extension Service succeed in its educational mission.

PROJECT PHILOSOPHY

The potential benefits of a demonstration project are enhanced by cooperator sites which are widely dispersed geographically. Such an arrangement makes the sites "visible" to more producers, allows evaluation of the several designs under a wider range of climatic conditions and should enhance the image of the sponsoring institution. At the same time widely separated sites severely complicate the management of construction and data collection. These drawbacks of widely scattered sites could in

large part be offset if adequate funding were available to allow employment of a full-time individual with freedom from class schedules and other obligations. Other requirements would be a funding level to cover required travel costs and to allow simultaneous monitoring of all sites.

Contractor and/or producer skill and familiarity with construction techniques and solar technology influenced construction cost variations between projects. In two projects (Paus and Stevens) extensive and thorough advance planning minimized construction site decision making and thus labor costs. Having demonstrated that system costs can be controlled, it is likely that as solar construction technology becomes more widespread among farm builders, additional opportunities to control or reduce system costs will become evident.

ECONOMIC FEASIBILITY OF SOLAR LIVESTOCK HEATING

The nature of this project did not lend itself to an accurate measurement of the economic benefits or savings from the investment in solar equipment. Since it was set up as a series of demonstrations, rather than a research project, there were no "control" or "conventional" systems with which to compare the solar systems. Also, gas, electricity and other inputs were generally not metered or measured separately for the solar-heated facilities. Therefore, only simple payoff tests have been calculated. The type of data available were not conducive to a more sophisticated economic analysis.

Since factors such as income tax and interest rates affect the outcome of an evaluation, but were not considered in the payoff tests, an example (See Table 1) is presented to show the impact of these factors. This example is based on an investment in solar equipment of $1,000. The farmer is in a 30 percent marginal tax bracket (state and federal) and the nominal interest rate is 14.3 percent. The investment in solar equipment qualifies for both the 10 percent investment tax credit and the 15 percent business energy tax credit. Under current depreciation guidelines (accelerated cost recovery system) the investment will be depreciated to zero value in five years.

The example in Table 1 shows that the tax savings can reduce the present value of the cost of $1,000 worth of solar equipment to $547.79. How much of a net savings per year would the solar equipment have to yield in order to break-even? Table 2 was calculated using the same interest rate (14.3 percent) and tax bracket (30 percent) as in the example presented in Table 1. It shows savings per year which would be required for the solar equipment to break-even in 5, 10 and 15 years.

The figures in Table 2 can be used as a guideline in evaluating systems where energy cost savings are estimated or collected. For example, a $7,000 investment in solar equipment would need to generate a savings of $623 ($89 x 7) per year in order to yield a pre-tax return of 14.3 percent, or an after-tax return of 10 percent over a 10 year period.

Table 1. Five-year economic analysis of solar equipment investment (example, per $1,000).

Year	Equipment Cost	Depreciation	Tax Savings From Depreciation	Tax Savings From ITC[1]	Tax Savings From BETC[2]	Net Cash Flow	Present[3] Value of Net Cash Flow
0	($1,000)					($1,000)	($1,000)
1		$ 150	$ 45	$100	$150	295	268.18
2		220	66			66	54.55
3		210	63			63	47.33
4		210	63			63	43.03
5		210	63			63	39.12
Total		$1,000	$300			($450)	($547.79)

[1]All of the solar equipment should qualify for the 10 percent investment tax credit. This does not reduce the basis for depreciation under current tax law, although this was changed in the tax law of August, 1982.

[2]This investment should qualify as solar energy property for the business energy tax credit. The rate was 10 percent from 10-1-78 through 12-31-79. It is 15 percent from 1-1-80 through 12-31-85. This credit is taken in addition to the regular investment tax credit.

[3]A pre-tax discount rate of 14.3 percent was assumed. Given the marginal tax bracket of 30 percent, an after-tax discount rate of 10 percent was used to discount the cash flows to their present value.

Table 2. Net annual savings required to break-even on solar investment (example, per $1,000).

Years	Required Net Savings Per Year
5	$145
10	89
15	72

SOLAR HEAT STORAGE

Use of solar heat storage in all of the solar collector systems was beneficial, except in the case of the grain drying mode of operation of the one vertical solar wall (Lay, NE-2). Storage of excess daytime solar heat allowed that heat to be released at night, when the heat was required because of lower outdoor ambient temperatures. The vertical solar walls provided the majority of their heat, and benefits to the livestock buildings, at night. The Solar MOF Nursery IFHDS systems effectively stored the excess daytime solar heat and moderated the floor temperatures to provide almost all of the heat required by the nurseries under normal operating conditions.

In development of solar collector system designs for the various systems, an effort was made to devise techniques to achieve the generally recommended storage mass and airflow rate to collector area ratios. Specifically, the goal was designs which would provide 2 ft^3 of thermal storage mass (standard density concrete, or equivalent) and an airflow rate of 2 cfm per ft^2 of collector. Although these specific goals were realized to varying degrees in the various systems designed and installed, the necessity of thermal storage as part of a system has been clearly demonstrated.

DATA COLLECTION AND ANALYSIS

Campbell Scientific CR5 Digital Recorders were used to monitor temperature and solar radiation data at the various sites. Cooper-constantan thermocouples at each site were wired to bus bars in junction boxes. Wires ran from these bus bars to 24 point TRW cinch plugs in the side of the junction boxes. Wires from the input terminals of the S250 50-channel scanner in the CR5 digital recorder connected these terminals to 24 point TRW cinch plugs mounted in the side of the Campbell recorders. Twelve-pair connector cables with a 24 point TRW cinch plug on each end served as extension/connection cords between the Campbell digital recorder and the junction boxes. This was our method of achieving mobility of the data loggers, since insufficient funds were made available to provide a data logger at each site.

Solar radiation levels were measured with Eppley Black-and-White Model 8-48 Pyranometers. These pyranometers were connected to A101MV millivolt integrator modules in the Campbell digital recorders. The pyranometers were not moved from site to site but were kept at the Solar MOF Nursery sites (Projects NE-1 and NE-10) since this system is unique to the Nebraska contribution towards this project.

Hourly recordings of the temperatures and solar radiation were placed on Scotch 835/2 Certified Digital Cassettes by the Campbell R235 CR5/ Cassette Interface module. Once every two to four weeks, the tapes were changed and data were entered into the IBM 370 computer at the University of Nebraska with a Campbell A235 Cassette/Terminal Interface.

Two accessory items we found desirable with the Campbell digital recorders were a printer disabling switch and a powered take-up roll. The printer disabling switch allows disconnection of the printer module

when data are being recorded on cassette tapes but allows personnel (either farm management or University) to easily spot-check all data points. The powered paper take-up roll prevented the fan-folded paper for the printer from being caught in and jamming the printer.

PROBLEMS

Several methods were used in an effort to determine airflow for mass flowrates through the solar collector systems. Static pressure differences were so low as to be negligible, except for the Solar MOF Nursery active solar collector systems. Air velocities were so low (less than 200 fpm) that hot wire anemometer readings were not precise. Vane anemometer readings at the outlet of the ventilation fans did not give satisfactory measurements of airflow through the vertical solar walls. Other, permanently mounted and recording airflow measuring devices such as a Thomasmeter were too expensive and time consuming to fit within budget and time constraints of the project. Consequently, mass flowrate and collected heat calculations were based on estimates of the airflow rate through the solar collector systems. To the extent possible, mass flowrate data were also based on manufacturer's fan performance data. However, the use of fans not subjected to AMCA testing makes the accuracy of these data questionable. Overall accuracy of airflow estimates could easily vary by ±30 to 50 percent. Thus, care must be exercised in use of performance data.

Lack of adequate budgeting for the projects resulted in having fewer data loggers than project sites. This prevented simultaneous data monitoring for all systems and prevented accurate comparisons between systems.

High interest rates and low hog prices at the beginning of the project resulted in several of our initial cooperators being unable to continue cooperation because of the cash-flow problems associated with installation of the solar collector systems. This forced us to locate other cooperators and delayed the system design and construction phase of the project. Lack of economic feasibility led to a decision by all dairy and poultry producers to stop consideration of solar heating systems for their production facilities. These problems resulted in a high turn-over of project cooperators, and increased design time and cost, as well as a delay in construction of some systems. Time constraints for the project did not allow collection of data for two heating seasons on many of these systems.

Cooperators themselves caused a few problems. One cooperator changed his mind regarding system design so frequently that he became dissatisfied with project personnel's inability to effectively meet all the changing design criteria. This cooperator was subsequently dropped from the project because of his dissatisfaction. Another cooperator had so many "irons in the fire" that he was unable to provide the management and labor required for his solar heated livestock building. In this instance the result was a total lack of operational data from that solar collector system.

Although an effort was made to "bridge the gap" between the Cooperative Extension Service and engineers engaged in consulting practices, a lack of solar system design expertise on the part of the consultants soon became

evident in time delays and project cost over-runs. Several cooperators found it difficult to communicate with the consultants. The overall result was this aspect of the project became an unpleasant experience for nearly everyone involved.

SUGGESTIONS

In many cases knowing more about less is better than knowing less about more. With the same level of funding each state could have been asked to provide information on four or five sites instead of ten. This would have allowed better instrumentation, simultaneous and continuous data collection--except for the ever-present system malfunctions--and much more confidence in the accuracy of the data produced. While this may seem on the surface to be more in the line of research than demonstration we feel the overall results of the project would have been more beneficial and rewarding.

The formal agreement between the sponsoring university and the cooperator is a good start at ensuring cooperation. Choosing of cooperators may need to be a careful selection process. In some instances county Extension agents might have sufficient familiarity with their producers to enable them to recommend farmers interested in the program, limiting recommendations to those believed to have the financial means and management skills to fulfill the cooperator's part of the program. The prospective cooperator and project manager or project team members then need to visit to assure that all personnel involved in the project are aware of the problems the farmer wishes to solve by cooperation in the project. The potential cooperator must also be made aware of his obligations to the project success. The project manager can then suggest solutions and determine the farmer's response to those suggestions. A visit by the project manager and/or project team members to each prospective cooperator's farm would be helpful for the project manager to assess the cooperator's management, labor and economic capabilities. It might be helpful for project personnel to visit with the prospective cooperator's banker to allow input from the banker regarding the financial capabilities of the farmer and his bank. The cooperators can then be chosen from the list of prospective cooperators. However, our experience suggests that even such thorough and complete screening procedures cannot guarantee success in the selection process. Problems such as animal or producer health, abrupt changes in market prices and similar events all comprise over-riding uncontrollable circumstances.

PROJECT UTILIZATION

1) Plan No. NE 10.726-37 was prepared from the successful Solar MOF Nursery (Projects NE-1 and NE-10). Over 300 copies of this plan have been sold. At least three of the nurseries are operating in Nebraska. Solar MOF Nurseries have also been built in eight other states in the USA. Pork producers in China and Korea are planning to construct Solar MOF Nurseries in their countries.

2) A 1:20 scale model of the Solar MOF Nursery has been built and used for displays at pork producer meetings, field days and fairs. The model visually depicts the Solar MOF Nursery and the features of the design.

3) A 1:20 scale model of a farrowing house with farrowing pens (Project NE-2) and crates (Project NE-5) with the slant solar wall and water heating option (Project NE-5) was constructed. This model also has been used at pork producer meetings, field days and fairs in the state.

4) Much of the design and performance knowledge gained from this project by University of Nebraska agricultural engineers was used in design of solar heated swine facilities (80 sow farrow-to-finish) at the University of Nebraska's Energy Integrated Farm Extension Demonstration Project. Aspects from the Solar MOF Nursery and vertical solar walls have been included and are on display. The "Energy Farm" is located at the University's Field Lab near Mead, NE.

5) Drafts of NebGuides (four page informational pamphlets for state-wide distribution) on Solar Collectors and the Nebraska Solar MOF Nursery are in final stages of review and preparation.

6) Three slide tape sets are being planned. Topics addressed will be: 1) Solar MOF Nursery; 2) vertical solar wall; and 3) overall demonstration project.

7) Knowledge gained from the project was included in an in-service training program for county Extension agents on the topic of solar energy for agriculture. Phase I final reports were given to the training session participants. A tour of four project sites was also part of the session.

8) Various installations associated with this project have been featured in at least six state and/or national swine trade and solar magazines.

9) A number of technical papers and articles have been prepared in which one or more of the demonstration project systems has been discussed. Papers prepared and presented are:

   a) Bodman, G.R., J.A. DeShazer, M.F. Kocher and J.A. Lamb. 1980. In-floor storage of solar heat. Technical Paper No. 80-4514. American Society of Agricultural Engineers, St. Joseph, MI.

   b) Bodman, G.R., J.A. DeShazer, M.F. Kocher and D.D. Schulte. 1981. Concrete floors for storage and distribution of solar heat. In Modelling, Design and Evaluation of Agricultural Buildings, Proceedings of CIGR Section II Seminar, Aberdeen, Scotland.

   c) Bodman, G.R., M.F. Kocher, J.A. DeShazer and J.A. Lamb. 1982. In-floor solar heat for swine nurseries. In Livestock Environment II, Proceedings of the Second International Livestock Environment Symposium, American Society of Agricultural Engineers, St. Joseph, MI.

d) Bodman, G.R. 1982. Swine nursery design--challenges and opportunities. In Proceedings George A. Young and Twenty-Second Annual Nebraska SPF Conference, University of Nebraska--Lincoln.

e) Kocher, M.F., G.R. Bodman and M.R. Lay. 1981. Solar grain drying and farrowing house heating with a multi-use collector. Technical Paper No. 81-4554. American Society of Agricultural Engineers, St. Joseph, MI.

f) Kocher, M.F., E.J. Veburg, G.R. Bodman, J.A. DeShazer and D.D. Schulte. 1981. Solar energy and swine confinement operation. 1981 Nebraska Swine Report E.C. 81-219. University of Nebraska-Lincoln.

g) Kocher, M.F. and J.A. DeShazer. Thermal performance of an in-floor solar heat distribution-storage system. (Proposed paper for the 1983 Summer ASAE Meeting. American Society of Agricultural Engineers, St. Joseph, MI).

PROJECT MANAGEMENT

Work on this report was performed by the University of Nebraska Department of Agricultural Engineering. Individuals directly involved with the project were Gerald R. Bodman, P.E., Extension Agricultural Engineer--Livestock Systems (Project Manager) and Michael F. Kocher, Extension Assistant (Project Coordinator). Inputs from the Departments of Agricultural Economics and Animal Science are acknowledged.

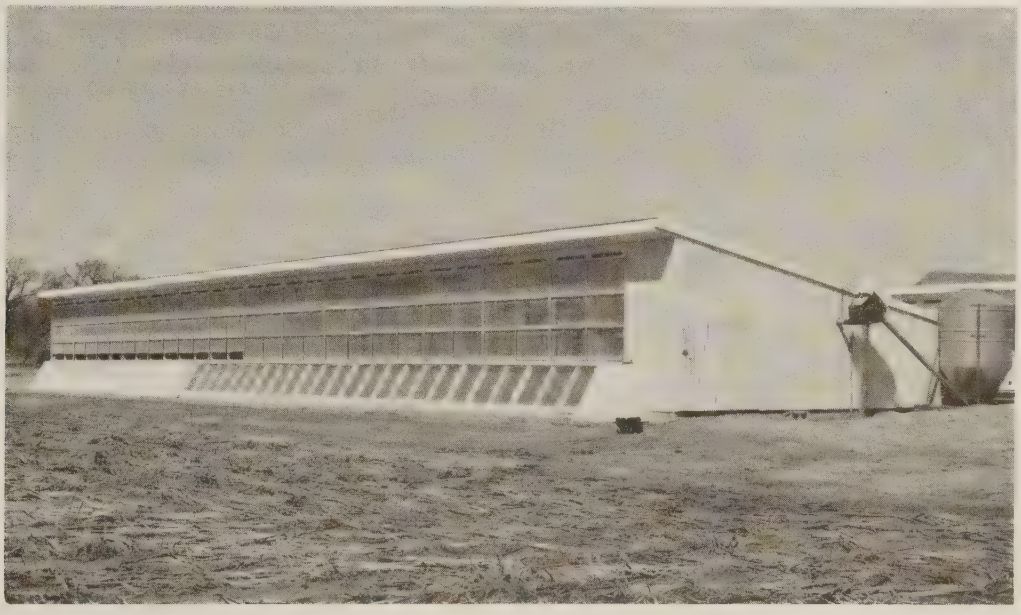
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MOF SWINE NURSERY WITH IN-FLOOR SOLAR HEAT

Alvin Paus and Sons, Art and Doug
Glenvil, NE

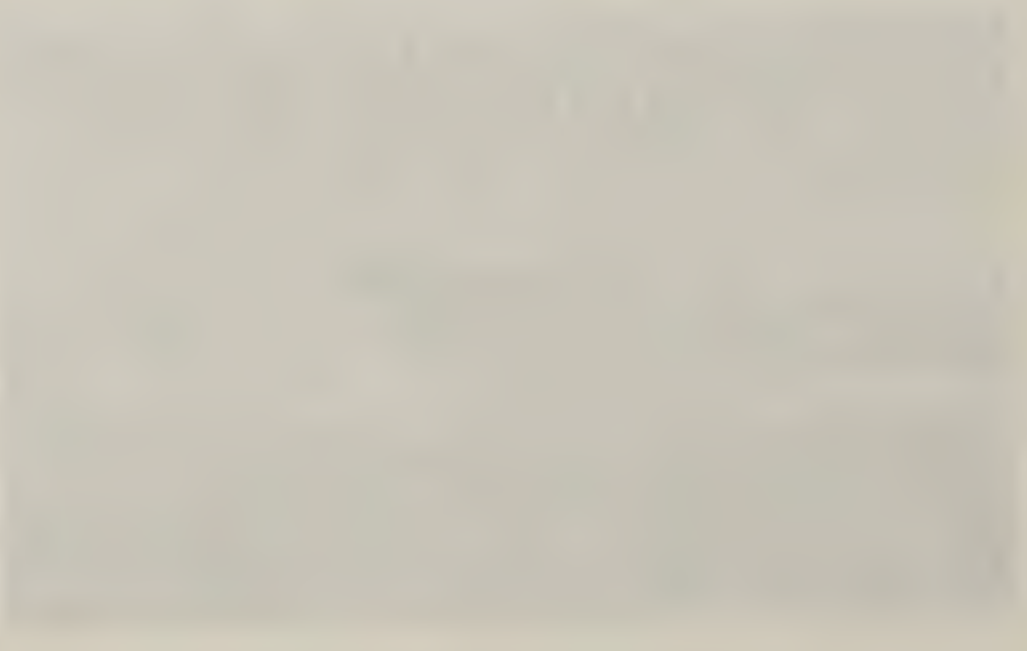
Demonstration Project
Solar Heating of On-Farm Livestock Structures
Project NE-1



550-head Solar MOF Nursery building with active/passive solar collector system and in-floor heat.

UNIVERSITY OF NEBRASKA-LINCOLN, COOPERATING WITH THE COUNTIES AND THE U.S. DEPARTMENT OF AGRICULTURE

The University of Nebraska-Lincoln The University of Nebraska Medical Center The University of Nebraska at Omaha



MOF SWINE NURSERY WITH IN-FLOOR SOLAR HEAT

Alvin Paus and Sons
Glenvil, NE

THE FARM

Alvin Paus and his sons, Doug and Art, own and operate the farm with the recent addition of the solar nursery. The farm (40°24'N, 98°11'W) is located in south central Nebraska's Clay County. The farming operation consists of working 880 acres, raising beef cattle and managing a 150-sow farrow-to-finish operation. The young pigs are weaned at about 4 weeks of age (15 lb) and are placed in the nursery until they reach a weight of approximately 60 lbs. At that time they are moved into a modified-open-front (MOF) growing-finishing unit. The Pauses produce approximately 2500 market hogs per year.

The Paus family has cooperated with the University of Nebraska, the U.S. Department of Agriculture and the U.S. Department of Energy in designing, constructing, instrumenting, and monitoring this system. This report includes a description of the nursery, a description of the solar collector system and the cost of the system. Some performance results, suggested modifications of the system and details on where to obtain plans for construction of a building similar to this one are also included.

GOALS

The design of the solar collector system was governed by the following objectives:

1) The solar collector system must be designed to allow the farmer or farm builder to construct the system with as much locally available material and equipment as is technologically and economically possible.

2) The system must be understandable and manageable by the farmer.

3) The system must be designed so the farmer can reasonably be expected to make any necessary repairs.

SYSTEM DESCRIPTION

A. The Solar Nursery

The 22-pen, 550-head nursery incorporates several energy conserving features besides the solar heating system. The 23 x 116 ft building has a mono-slope roof, is non-mechanically ventilated and is well insulated (See Table 1 for recommended R values). The solar heating system uses in-floor heat for zone heating--heating the floor of the sleeping area and allowing the warm floor to heat the pig's immediate environment. Insulated hovers are used to help retain heat within the pig's environment. The in-floor heat and insulated hovers are located in the rear 40 percent of each pen. Feeders in the pen partition walls are located in the middle portion of each pen. Manure is removed from the building via an open flush gutter located along the south end of the pens and equipped with a dosing siphon flush tank(See Figure 1).

B. The Solar Collectors

Supplemental heat for the nursery building is supplied by a combination of active and passive solar collectors. The passive collector system consists of 8 x 6 ft windows along the south wall. Solar energy passing through these windows is absorbed by the 3 in. concrete floor which is insulated from the underlying soil. The passive windows are approximately 3 ft above exterior grade level, allowing room for the active collector beneath them.

The single-pass, 3 ft-3 in. x 108 ft active collector is sloped 60 degrees from the horizontal to allow maximum winter solar energy collection. The active collector heats air which travels through the collector, through the heat storage, and returns to the collector in a closed loop arrangement (See Figure 2). The airflow rate through the active collector system is approximately 2.3 cfm per ft^2 of collector.

The In-Floor Heat Distribution-Storage (IFHDS) system for the active collector consists of a layer of concrete blocks laid on edge with the cores aligned to provide air channels along the length of the building (See Figure 3). The heat storage is five 2-core 8 x 8 x 16 in. (nominal) blocks wide with a 7 to 10 in. sand layer above the blocks and a 3 in. concrete floor above the sand. The IFHDS system is insulated to prevent excessive heat loss to the soil below the building. The resultant storage capacity is approximately 2 ft^3 per ft^2 of collector.

C. Non-Mechanical Ventilation

The non-mechanical ventilation system is another energy-saving feature of the nursery. Fall, winter and spring ventilation is achieved through adjustment of the openable passive collector windows and an air outlet near the top of the south wall. Openable panels along the north wall facilitate increasing airflow through the animal space during warm weather. Airflow under all weather conditions is augmented by the 3:12 roof slope.

D. Model

To aid producers in visualizing various components of the system a 1:20 scale model of the facility was constructed. All aspects of the field unit are illustrated in the model. The model has been used extensively at producer meetings, fairs and field days.

COST

The passive and active collector and the IFHDS system added a total cost (materials and labor) of $6,945.92 to the cost of the building. The passive panels cost $2,739.80 for 672 ft^2 or $4.08 per ft^2. The 351 ft^2 of active collector and the IFHDS system cost $4,206.12 or $11.98 per ft^2 of collector. The owner estimates the glazings on the active collector will last 10 years with the remainder of the system lasting 15 to 20 years.

The total cost of the building, including the solar heating system, was $30,000.00. A non-solar MOF nursery would have cost $30,000.00 less the $6,946.00 for the solar heating system. However, additional costs would have included approximately $1,500.00 for a curtain or similar covering for the front opening (where the passive windows are now located) and a minimum of $500.00 for a forced warm air furnace system for a total of $25,054.00. The solar collector system therefore added 16.5 percent to the basic cost of the building. Despite the added cost for the solar collector system, the total cost of the facility at $54.55 per pig was less than two-thirds the cost of a conventional raised deck style nursery at the time of construction.

PERFORMANCE

A. Thermal

The Pauses have been pleased with the performance of the building. Under their expert management, the building has functioned to provide an environment conducive to good performance of young pigs--and has done so at low cost--since the building was occupied in October 1979.

Some aspects of the thermal performance of the solar heated nursery are presented in Table 2. During the months noted, the total quantity of solar heat delivered to the surface of the solar heated floor (top of the IFHDS system) ranged from 1.70×10^6 Btu to 4.09×10^6 Btu with an average of 2.94×10^6 Btu per month. This solar heat, plus the heat from the pigs themselves, kept monthly average air temperatures under the hovers between 73 and 82°F with an average of 77°F.

The thermocouple used to measure the air temperature beneath the hover was under the middle of the hover of the first pen in the building (east end). The smallest pigs were kept in this pen since the air from the collector, having just entered the IFHDS system at this location was hot enough to keep the floor surface temperature between 90 and 95°F most of the time.

The thermocouple used to measure the indoor ambient temperature was in the middle of a pen near the midpoint of the building. This thermocouple was 5 ft above the floor (not in the pig zone). Temperatures at this point (human "eye level") averaged 7F° cooler than temperatures in the pig zone under the hover. This demonstrates the advantage of hovers and in-floor heat in energy savings since the whole building interior need not be heated to the high temperature required by the young pigs. This design reduces conductive heat losses through building surfaces while meeting the thermal needs of the young pigs. The use of hovers over the heated floor, a cooler open feeding area, and a cooler flush gutter area also allowed pigs to choose between three micro-environments to fit their thermal needs.

The total solar heat transferred to the floor surface as presented in Table 2 was calculated on an hourly basis from the temperature loss of the air going through the IFHDS system and a collector system airflow rate based on AMCA certified airflow data at the measured static pressure drop across the fan. Heat losses to the soil around the IFHDS system as calculated from temperature differences in the soil were then subtracted from the heat input to the IFHDS system to determine the quantity of solar heat transferred to the floor surface. The hourly heat transferred to the floor surface was accumulated to obtain the monthly totals. Dividing monthly totals by the number of days in the month and the collector area yielded the average daily heat input to the floor per square foot of collector area. This value divided by the average daily solar insolation incident on the collector yielded the percent of solar energy actually transmitted to the floor surface. This percentage was about 20 percent for normal conditions, with a decrease to about 13 percent in cold weather.

During the first three years of operation solar heat provided 100 percent of the supplemental heating needs of the building except for four weeks during late December 1981 and early January 1982. During this time period heat lamps were used in pens occupied by newly weaned pigs to maintain warm temperatures during the cold cloudy weather (Table 3).

It is not known whether all of the heat supplied by the solar system in the "100 percent solar heated" months was needed. If excess heat was added to the building by the solar heating system it was removed from the building with increased ventilation. With a non-mechanically ventilated building, accurate comparison of the supplied solar heat and heat actually required is not possible.

In February of 1980, the temperature of the air leaving the solar collector regularly peaked at 140°F on sunny days (See Figure 4). The temperature of the air entering the collector during this same time period normally peaked at about 78°F. Outdoor temperatures for the period were between 15 and 50°F. Indoor ambient temperatures during this period were between 45 and 75°F.

Although the indoor ambient temperature fluctuated, the temperature of the floor surface in pen 2, occupied by the smallest pigs, remained nearly constant at about 90°F (See Figure 5). This constant floor temperature reflects the temperature moderating and heat storage effects of the

IFHDS system. The moderating and storing effects can be seen by comparing the relatively constant temperature of the floor surface at 90°F to the periodic temperature pattern of the air passing through the air passageway in the concrete blocks. The air passing through the IFHDS system at this location reached a peak temperature of about 127°F during sunny hours and cooled to about 85°F overnight.

Note that the temperature of the air at the far end of the building (pen 21) just before the air leaves the IFHDS system and returns to the collector does not have a large temperature rise associated with sunny hours. This air has travelled the length of the IFHDS system and has already transferred much of its heat to the storage mass. There is enough heat at this location from the IFHDS system, and from the larger pigs (40-60 lbs) themselves, to keep the environment in this pen warm enough for these larger pigs.

B. Economic

An engineering heat balance was performed for this building. Estimated annual heating costs were $1540 if petroleum-based fuels and conventional whole-building space heating techniques were used. This cost is based on a propane price of $0.56 per gallon. During the heating seasons of '79-'80 and '80-'81 (September thru April) the only supplemental heat added to the building was solar heat. The operational cost of the solar system was equal to the cost of electricity to run the fan in the active collector. This cost came to $10 and $20 for the respective heating seasons. During late December 1981 and early January 1982 low solar insolation levels made it necessary to add heat lamps to the first five pens for newly weaned pigs. The operating costs for these heat lamps over a 30-day period resulted in an increase in unit operating costs for the heating season of '81-'82 to approximately $55. Nearly two-thirds of this operating cost was for electricity used by heat lamps.

Assuming the $1540 per year conventional heating costs and using the $6,945.92 cost for all of the solar components, the simple payback period can be calculated at 4.6 years. This payback period can be reduced to between 3 and 5 years with tax credits, a time-value-of-money approach to calculating the payback period and with current propane prices.

C. Ventilation System

All ventilation openings are manually adjusted. During three years operation this control technique has been found to be both efficient and effective. Automatic controls were determined to be unsatisfactory due to freezing of the panels. Openings are usually adjusted as needed during morning and evening checks of the facility and animals. The manually adjusted openings in combination with the three micro-environments within each pen have served to allow ventilation rates to be varied to meet the needs of various size pigs.

Adjustment of the south wall air inlets (passive solar windows) is accomplished by a hand crank and winch system. Groups of panels along each third of the building can be independently adjusted. The air outlet along the top of the south wall stays open except for extreme winter weather. North wall panels are opened and closed as necessary.

D. Maintenance

The solar heating system does require some maintenance. Dust must be washed off the active collector glazings about once a month, especially when peak solar heating is required (i.e., when a group of newly weaned pigs enters the building). The solar collector fan bearings must be greased and belt tension checked. Glazings must be checked for damage after bad storms or, just generally, about twice per year. The active collector must be covered at the beginning of the summer to prevent overheating the building and the collector. The wood on the exterior of the collector should be kept protected with paint. Joints in the collector system should be inspected occasionally to be sure they are tightly caulked to prevent air leaks. Attempts by rodents to enter the system should be repaired.

E. Problems

Most of the problems encountered in this building were related to data gathering as contrasted to problems with the building. Several pigs escaped from their pen one day and chewed through several thermocouple wires. The thermocouple under the hover was also subjected to pig chewing. From these experiences, it is suggested that thermocouple wiring in places where the pigs might conceivably gain access to the wire should be in conduit, pipe or junction boxes. If the sensing end of a thermocouple must be in a pig zone, run the thermocouple wire down a conduit with holes or slots. This allows airflow over the sensing end without allowing pigs to chew on the wire.

Thermocouples weren't the only things that had problems. Moisture, dust and the generally corrosive atmosphere in the building necessitated removal of the data logger every two or three months for cleaning, calibration checks and repairs. The plugs connecting the thermocouples to the data logger corroded and several connectors had to be replaced after severe errors were identified in the data.

One problem with the active solar collector system, noticed from the data early in the project, was a large temperature drop (30F°) in the solar heated air between the outlet from the collector and the inlet to the IFHDS system. A similar temperature drop was noticed at the other end of the collector, between the outlet from the IFHDS system and the inlet to the collector. These problems occurred during collector operation. Doors in the ends of the collector allowing access to the collector for instrumentation, inspection, etc. were caulked shut to reduce air leaks. This measure reduced the large temperature drop, but did not completely solve the problem. We believe increasing the level of insulation from R 4 to R 15 for all surfaces of the transition boxes between the solar collector and the PVC pipes will reduce the temperature drop at these locations to a reasonable level of about 10F°. Be sure to use a high temperature insulation in these locations.

Other problems noticed from the data were gradual overnight temperature decreases at the active collector inlet and outlet, and at the inlet and outlet of the IFHDS system. These temperature drops occurred overnight, whereas the previously mentioned problem occurred while the collector was

operating. These overnight temperature decreases paralleled the outdoor ambient temperature, with the collector outlet temperature between the floor inlet (air passageway, pen 2) and outdoor temperatures (See Figure 6). Additionally the temperatures are higher at the outlet end of the collector than at the inlet end. We believe natural convection currents at each end of the building are set up by the density differences between the warm air at the IFHDS system and the cold air at the collector. The convection currents are causing the temperature decreases in the air at the IFHDS system. To prevent these convection currents and the associated heat loss from the IFHDS system, we recommend placing back-draft dampers at the outlet ends of the PVC pipes. The recommended back-draft dampers are pieces of plastic that can withstand temperatures as high as 200°F without deforming (See Figure 7). A layer of high temperature fiberglass insulation should be attached to the plastic sheet to reduce conductive heat transfer from the air in the IFHDS system to the air in the PVC pipes during these overnight periods.

COMMENTARY

A. Construction Suggestions

1) Plan No. NE 10.726-37 Solar MOF Nursery is available from the University of Nebraska Agricultural Engineering Plan Service for $5.00 and provides information needed to construct one of these buildings. The plan packet includes guidelines regarding construction techniques and materials, solar energy, equipment selection and system management. One specific construction procedure is to completely seal the active collector system against air leaks during construction. Collector performance is highly dependent on having an airtight system. It is much easier to build properly the first time than to repair air leaks. Use only high quality, long-life caulking materials. Clear silicone caulk is recommended.

2) Care should be taken to prevent creasing of the Tedlar® glazing during construction of the active collector. The Tedlar® does not crease easily, but will crease if a heavy object is laid on a fold. The creases are weaknesses in the Tedlar® sheet and tearing might occur as the Tedlar® shrinks in very cold weather.

3) Glazing material for the collector should be chosen to withstand ultraviolet light degradation and to have good solar energy transmission characteristics.

4) Install the fan and back-draft dampers in a manner that allows for servicing and repair. The fan and transition should be placed in an "empty pen" to allow easy access, proper heat delivery to the floor of the first pen with small pigs, and space for equipment storage.

5) Use a high temperature fiberglass insulation board in the active collector behind the absorber plate to prevent "failure" of this insulation. Plastic foam insulations in this location will "melt".

Normal fiberglass insulation in this location will experience decomposition of the organic binder or "glue" holding the fibers together. This decomposing binder will give off a gas that will "cloud" the inside of the glazing and reduce transmittance of solar energy to the absorber plate.

6) Placement of the fan to provide a suction at the collector outlet is recommended. In this arrangement, leaks allow cold air into the collector. Alternately, with the collector under pressure from the fan, a leak near the collector outlet could result in warmed air being pushed outside. Cold air leaking into the collector is more easily detected with temperature sensing equipment than is warm air leaking out.

7) With the recommended fan placement, the fan must be constructed so that its motor is remote from the airstream. Hot air from the collector will be passing through the fan, but most electric motors are not built to take the high temperatures from these solar collectors. A belt driven fan is almost mandatory in this situation.

8) The remote sensing bulb for the thermostat that controls the collector fan should be located in a shady spot near the collector outlet. The suggested location is in the upper half of the collector height and one to two inches from the edge of the solid cover used to form the transition.

9) When building the transitions from the collector to the PVC pipe (or equivalent) ducts, and from the PVC pipe (or equivalent) through the fan to the concrete blocks, be sure to insulate the transitions well. Insulation at these locations will reduce heat loss and prevent the fan motor from being overheated. High temperature insulation should be used.

10) The ventilation openings along the top of the south wall must be equipped with baffles or other devices to allow partial closure during extreme winter weather. The closure devices are especially needed during periods of low temperatures and strong north or south winds. North winds tend to over-ventilate the nursery by drawing warm air out the openings while south winds force excess amounts of cold air in through the openings.

B. Suggested Modifications

1) Use back-draft dampers at the outlet ends of the PVC pipe air ducts to prevent convection currents removing heat from the IFHDS system at night. A small flap of plastic that can withstand temperatures as high as 200°F (See Figure 7) can act as a gravity shutter to provide this back-draft damper. Attach a piece of high temperature insulation to the plastic sheet to reduce conductive heat losses.

2) The optimum collector and IFHDS system length seems to be in the 50 to 75 ft range. Multiples of these lengths are suggested for longer buildings with small pigs in the 15 to 30 lb category.

3) Buildings with lengths of 100 to 150 ft with pigs ranging from 15 to 50 lbs may need only one active collector loop. The smaller pigs may be kept above the solar IFHDS system. The smallest pigs should be kept in the pens where the air in the solar IFHDS system is warmest (i.e., pens closest to the place where the hot air from the collector enters the solar IFHDS system). As the pigs grow they should be moved through the building towards the area where the air in the solar IFHDS system is cool (i.e., pens closest to the place where the air leaves the solar IFHDS system and returns to the collector). The rest of the building need not have the active collector system but research results indicate heat storage may be beneficial. This insulated thermal storage can be identical to the solar IFHDS system except the concrete blocks are not needed because no air will pass through this heat storage. The insulated thermal storage mass will help store heat released from the animals at night as they lie on this storage area. Some of this heat is slowly released to the air during the day. The remainder of the heat stored in this area is used to maintain or slightly increase the average floor temperature above this heat storage. The research data referred to herein were reported in a technical paper (No. 80-4514) of the American Society of Agricultural Engineers.

4) Provisions to allow placement of heat lamps above the sleeping area in one-fourth of the pens are recommended. These heat lamps should be provided for the pens in which the smallest pigs will be located (i.e., closest to the place where hot air from the collector enters the solar IFHDS system) on an "as needed" basis. Experience with this unit has shown that use of these heat lamps was all the auxiliary heat required during the fourth coldest January on record (January 1982) in Nebraska. This cold weather was accompanied by low solar insolation levels during the months of December and January.

5) Caution should be taken in constructing a unit of this design in locations outside Nebraska. Certain features may need to be modified to accommodate local climatic conditions. For further information on the application of solar energy in your state contact your county Extension agent or Extension Agricultural Engineer at your Land-Grant University.

PROJECT MANAGEMENT

Work on this report was performed by the University of Nebraska Department of Agricultural Engineerng. Individuals directly involved with the project were Gerald R. Bodman, P.E., Extension Agricultural Engineer--Livestock Systems (Project Manager) and Michael F. Kocher, Extension Assistant (Project Coordinator). Inputs from the Departments of Agricultural Economics and Animal Science are acknowledged.

Table 1. Recommended types and levels of insulation for the Nebraska Solar MOF Nursery (Paus).

Insulation Location	Insulation Type	Insulation Level
Ceiling/roof	Fiberglass batt	R-19
Stud Wall	Fiberglass batt	R-11
Insulated concrete sandwich panel	Rigid foam board	R-13
Foundation perimeter	Extruded foam board	R-8
Beneath feeding floor	Extruded foam board	R-4
Around IFHDS system	Extruded foam board	R-8
Around solar collector air ducts	Fiberglass Batt	R-11
Behind solar collector absorber plate	High temperature fiberglass*	R-8
Transitions between air ducts (PVC pipe) and collector outlet and inlet	High temperature fiberglass*	R-15
Transition between air ducts and fan	High temperature fiberglass*	R-12
Transition between fan and IFHDS system	High temperature fiberglass*	R-12
Outlet end of air ducts (back-draft damper)	High temperature fiberglass*	R-4

*High temperature fiberglass is necessary to prevent this insulation from degrading at the temperatures attainable in the collectors.

Table 2. Thermal performance results for the Solar MOF Nursery (Paus).

	1980			1981						1982
	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	OCT.	NOV.	DEC.	JAN.
Total solar heat transferred to floor surface, 10^6 Btu	4.09	3.56	2.35	3.01	1.91	3.94	3.64	2.95	2.21	1.70
Avg. daily radiation incident on collector, Btu/ft^2·day	1798	1622	1082	1622	1565	1435	1366	1237	1118	1149
Avg. daily heat input to floor surface, Btu/ft^2 collector area·day	376	338	215	276	194	362	334	281	203	156
Avg. temp under hover, °F	82	77	75	78	NA	NA	NA	73	83	84
Avg. inside temp, °F	75	70	70	70	67	62	70	67	59	57
Avg. outside temp, °F	47	38	33	30	21	36	42	38	17	8
Solar energy transmitted to the floor surface, percent	20.9	20.8	19.9	13.3	12.4	25.3	24.5	22.7	18.2	13.6
Heat supplied by solar, percent	100	100	100	100	100	100	100	100	83.7	43.1

NA--not available

Table 3. Weather data near the Paus unit.

	1981			1982		
	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.
Average monthly temperature, °F	49	41	26	15	22	35
Departure from normal average monthly temperature, F°	-4	2	-3	-9	-4	0
Heating degree days, F°·days	461.5	712	1218.5	1549	1200.5	928
Normal heating degree days[1], F°·days	326	780.5	1146.5	1271	993.5	837
Percent possible sunshine[2]	50	57	39	40	61	50
Normal percent possible sunshine[1]	67	57	52	57	59	59

Source: Data from NOAA Climatological Data for Nebraska for the Weather Station at Clay Center, NE, 12 miles northeast of the unit.

[1]Taken from Climatic Atlas of the United States, 1968.

[2]NOAA data for the weather station at the airport in Lincoln, NE. Solar radiation at the two sites is consistently similar.

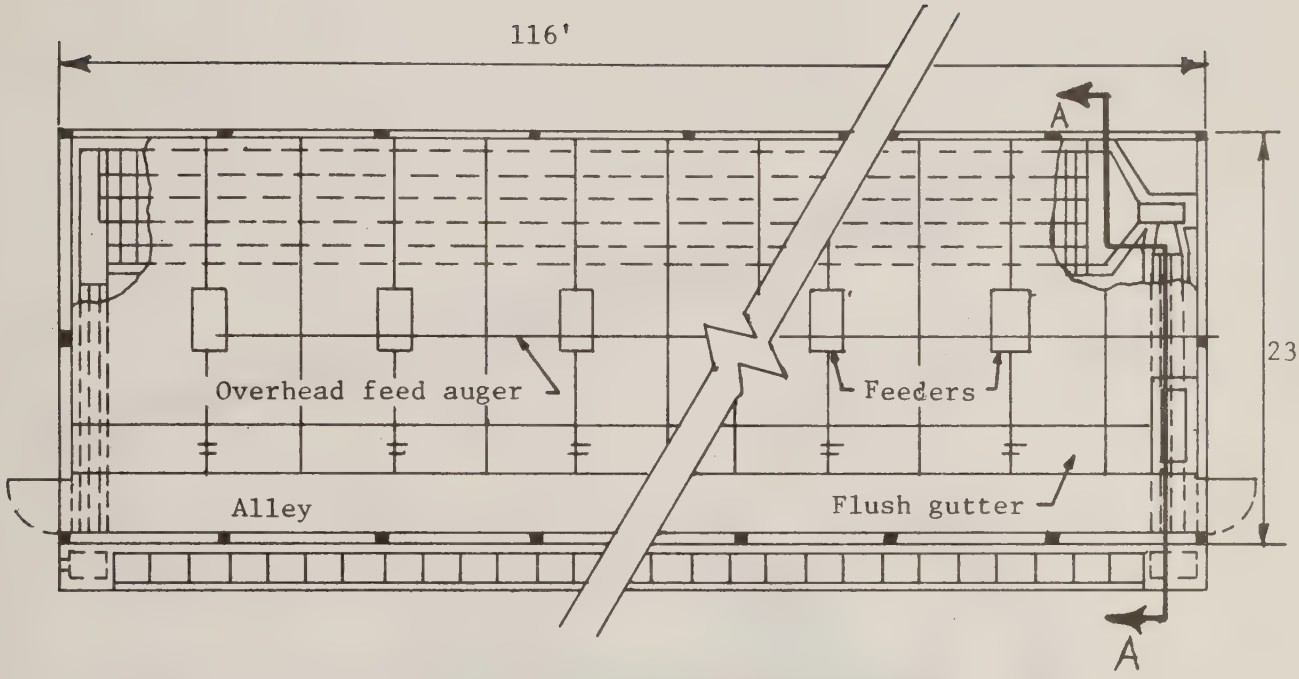


Figure 1. Solar MOF Nursery floor plan (Paus).

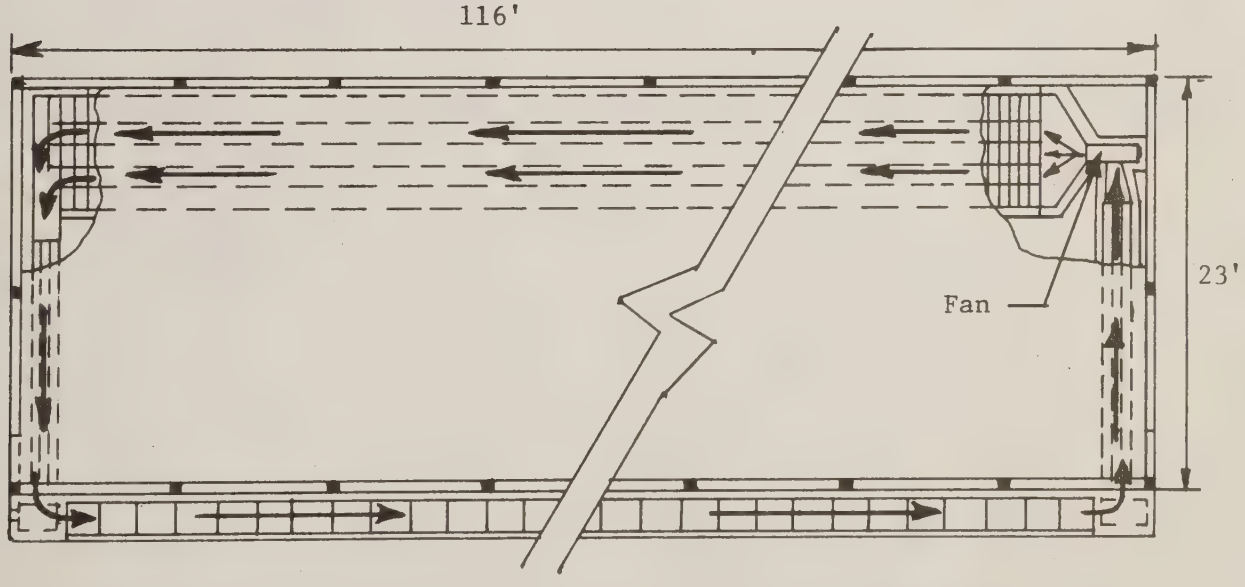


Figure 2. Fluid flow through the active solar collector system (Paus).

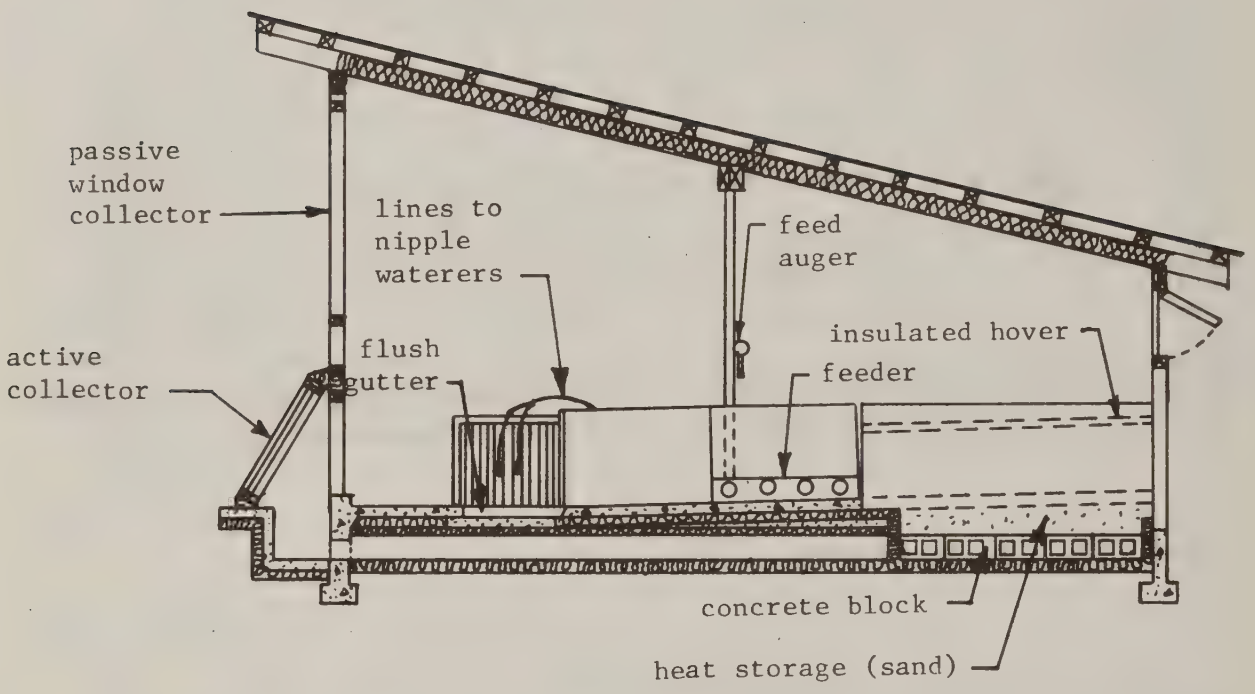


Figure 3. Solar MOF Nursery cross section (Paus).

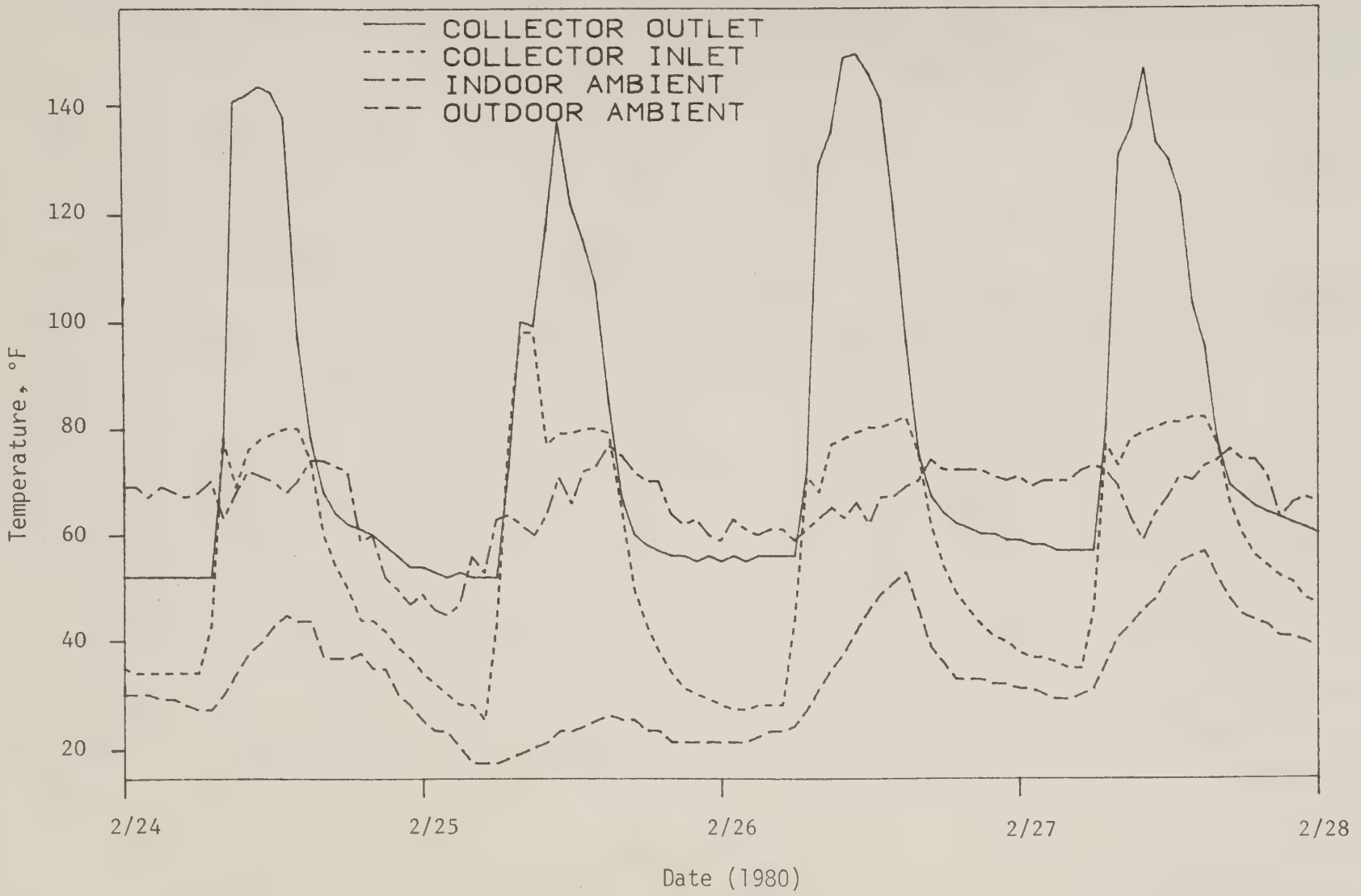


Figure 4. Collector and ambient temperatures at the Solar MOF Nursery in February 1980 (Paus).

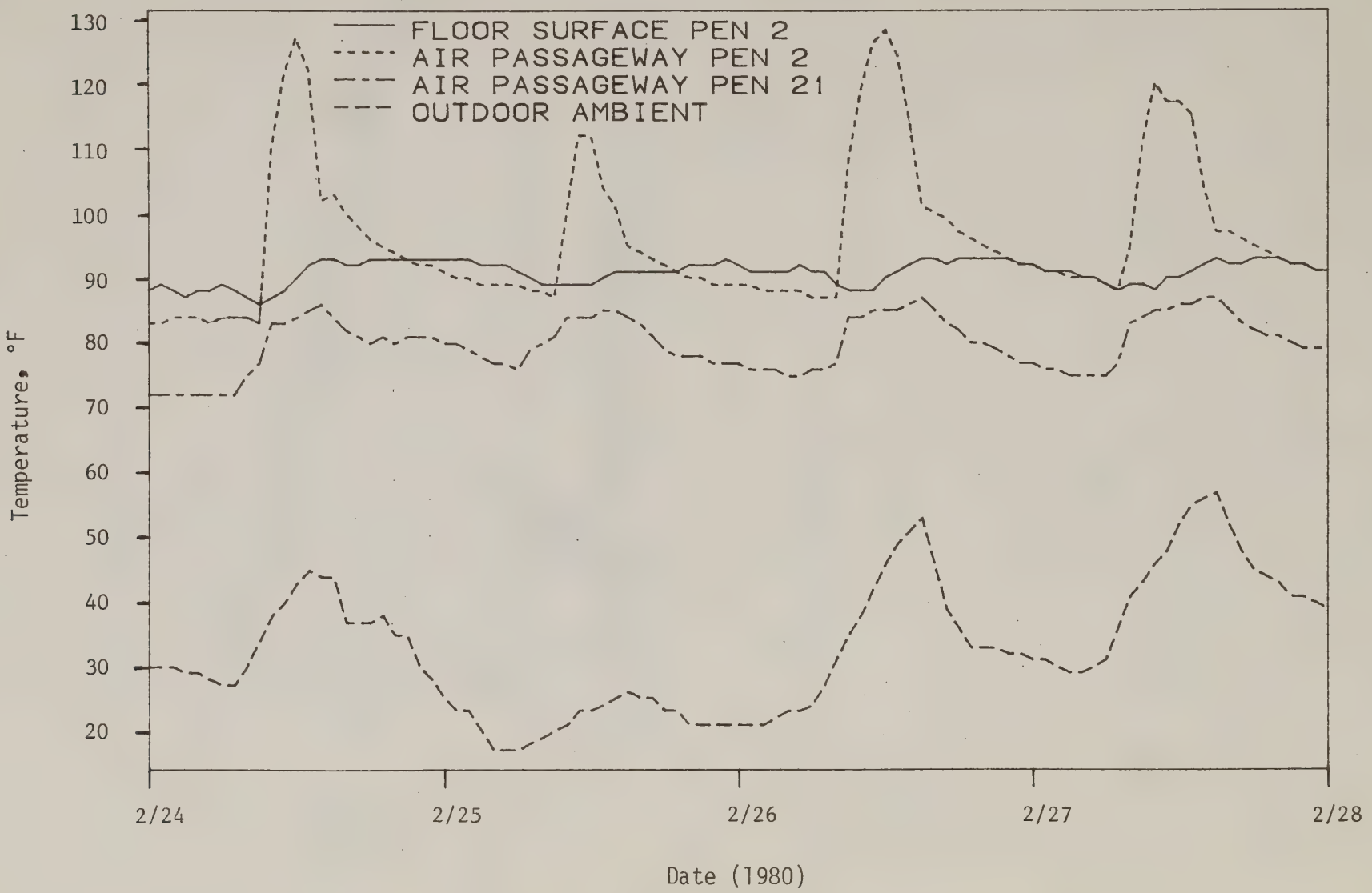


Figure 5. Temperatures at locations in the in-floor solar heat distribution-storage system in February 1980 (Paus).

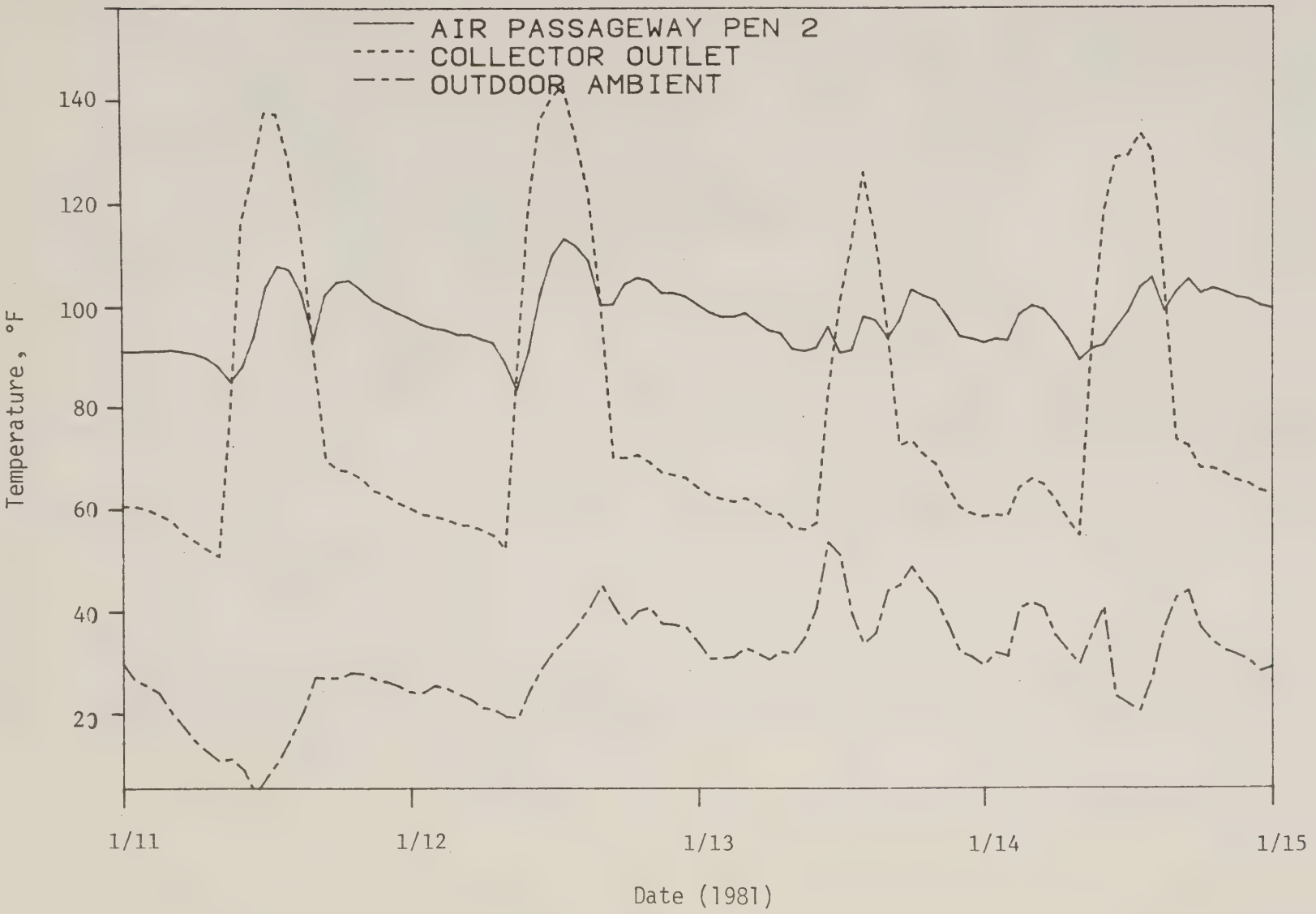
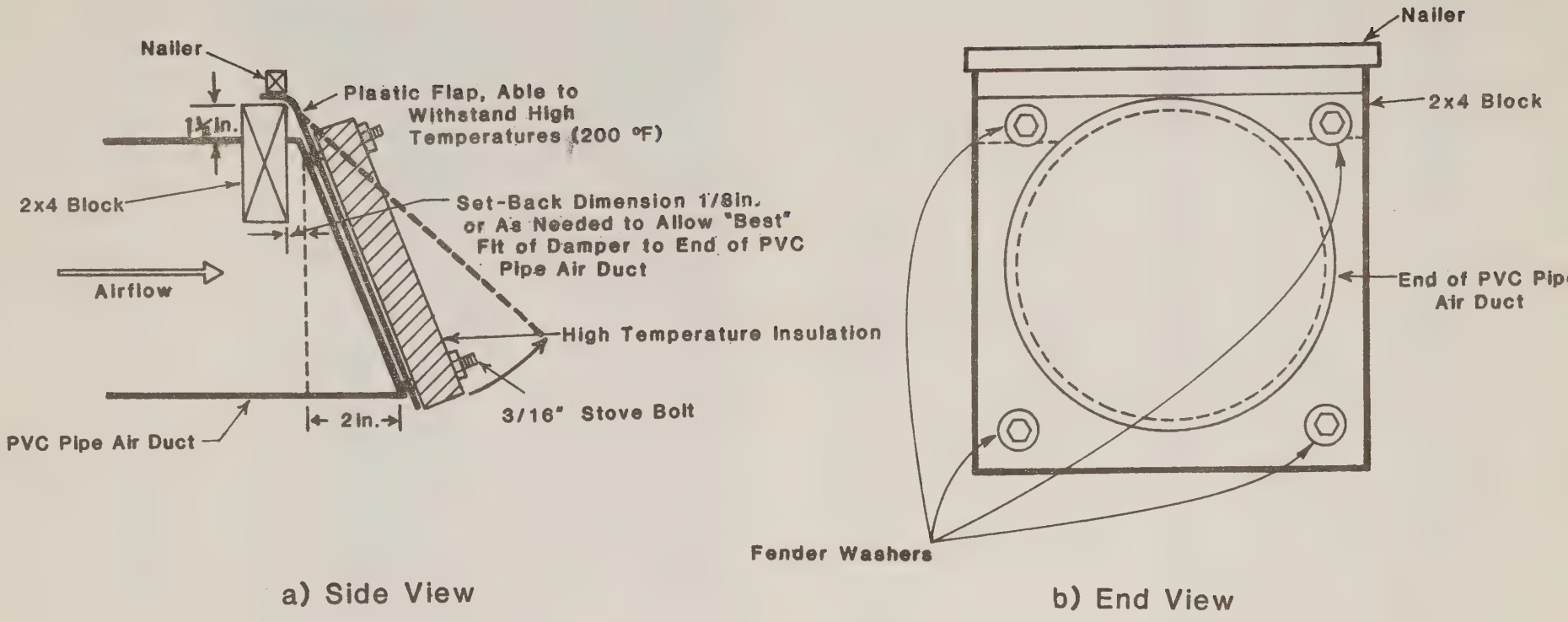


Figure 6. Temperatures in the in-floor solar heat distribution-storage system at the outlet end of the active solar collector (Paus).



NOTE: Use clear silicone caulk "adhesive" between the 2 x 4 block and the PVC pipe air duct to hold the block in place. Also use a bead of silicone caulk on either side of the plastic flap between the 2 x 4 block and the nailer. Place silicone caulk between the washers and the plastic flap and between the insulation and the plastic flap.

Figure 7. Back-draft dampers recommended for outlet ends of PVC pipe air ducts (Paus).

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SWINE FARROWING-NURSERY BUILDING WITH VERTICAL SOLAR WALL

Merlyn Lay
Glenvil, NE

Demonstration Project
Solar Heating of On-Farm Livestock Structures
Project NE-2



Farrowing-nursery building (2-25 pen rooms) and gestation room (50 sows) with solar collector to preheat ventilation and grain drying air.

UNIVERSITY OF NEBRASKA-LINCOLN, COOPERATING WITH THE COUNTIES AND THE U.S. DEPARTMENT OF AGRICULTURE

The University of Nebraska-Lincoln | The University of Nebraska Medical Center | The University of Nebraska at Omaha

SWINE FARROWING-NURSERY BUILDING WITH VERTICAL SOLAR WALL

Merlyn Lay
Glenvil, NE

THE FARM

Merlyn Lay owns and operates the farm on which this demonstration facility is located. The farm (40°29'N, 98°20'W) is located in south central Nebraska's Adams County. The farming operation consists of working approximately 900 acres, raising a few cattle and raising Specific Pathogen Free (SPF) pigs. The Lays have been involved in the SPF swine program for approximately 25 years. With the recent addition of two 25-sow farrowing-nursery units and a 50-sow gestation unit (occupied January 1, 1979) the breeding herd has been increased from 50 to 120 sows. Most of the pigs produced are finished to market weight. Pigs in excess of the capacity of a growing-finishing unit are sold for breeding and/or as feeder pigs.

The Lays have cooperated with the University of Nebraska, the U.S. Department of Agriculture and the U.S. Department of Energy in designing, constructing, instrumenting, and monitoring this system. Presented in this report is information on a solar system used to preheat ventilation air for the farrowing-nursery rooms during the winter, cool ventilation air during the summer and warm air for grain drying in the fall. The information includes a description of the farrowing house, the grain drying system, and the solar collector. Guidelines for operating the system, suggested system modifications and typical results of the system performance evaluation are also included.

GOALS

The design of the solar collector system was governed by the following objectives:

1) The solar collector system must be designed to allow the farmer or farm builder to construct the system with as much locally available material and equipment as is technologically and economically possible.

2) The system must be understandable and manageable by the farmer.

3) The system must be designed so the farmer can reasonably be expected to make any necessary repairs.

SYSTEM DESCRIPTION

A. The Farrowing-Nursery Building

The two 24 x 59 ft farrowing-nursery rooms are connected end-to-end with the gestation room within one building. The building has a gable roof and each room is individually mechanically ventilated. Each farrowing-nursery room has twenty-five 4 ft-6 in. x 10 ft pens with the rear 6 ft of each pen floor being slats or woven wire over a deep pit designed to allow periodic "flushing" of manure into a nearby lagoon. The front 4 ft of each pen is a solid concrete floor creep area with in-floor warm water lines to provide a warm floor creep area for the young pigs. Heat lamps are used for the first few days after farrowing to provide additional heat for the newborn pigs and to attract the newborn pigs to the warm creep area.

Ventilation consists of over-the-wall slot inlets with three AMCA rated variable speed exhaust fans in each room located in a bank centered along the north wall (See Figure 1). The winter ventilation fan runs continuously and pulls air down through the slats where it moves across the manure in the pits before being exhausted from the building. Spring/fall ventilation follows a similar flow path (See Figures 2 and 3). The summer ventilation air is not drawn through the pits. Instead it is moved across the animal space and exhausted directly from the building rooms (See Figures 4 and 5). This arrangement provides for control of pit odors and gases while providing cooling of the sow.

B. The Solar Collector System

The solar collector consists of a vertical wall of dry-stacked concrete blocks with two glazing layers (Filoplate® #556). The blocks are 8 x 8 x 16 in. (nominal) concrete blocks placed so the long dimension is perpendicular to, and 15 in. away from, the south wall of the building. A 3/8 in. vertical gap between adjacent blocks allows airflow through the block wall. The south side of the block wall is painted black to increase the absorption of solar energy. Overall collector dimensions are 6 ft-8in. x 140 ft (932 ft^2).

The slots and gaps in the collector glazings and blocks are designed so winter ventilation air enters the collector between the glazings, travels across the warm black surface of the block wall, filters through the gaps between the blocks, and goes into the building through the ventilation air inlets. The ventilation fans exhausting moisture, gases, and odors continually pull ventilation air through the collector into the building. In this way, the building ventilation fans provide the power to move air through the collector instead of having a separate fan perform this function. The concrete blocks act both as absorber plate and heat storage. The blocks used to form the collector-storage were FHA blocks which are three quarters solid concrete. The indentions in the blocks in the east half of the collector were filled with sand to provide added heat storage capacity. The blocks in the west half of the collector do not have sand in the indentations.

The system is constructed so the collector can preheat winter ventilation air as well as cool summer ventilation air. Assuming a 35 cfm per sow normal winter ventilation rate, the collector airflow rate is 2.25 cfm per ft^2. During the fall, ventilation air can bypass the collectors through openings over the collector. This allows the collector to be used to heat air for use in grain drying (See Figures 4 and 6).

C. The Grain Drying Operation

A 27 ft-9 in. diameter grain bin with a full-perforated floor is used for drying grain. Corn at 26 to 28 percent moisture (wb) is loaded into the bin to a depth of approximately 4 ft. Drying air moves through the collector into a plenum between the concrete block wall and the farrowing-nursery building wall. The air exits out the east end of the plenum and moves down an enclosed walkway to the air inlet of the grain bin fan. The enclosed walkway is covered with a single layer of corrugated glazing (Filoplate® #556) so the walkway itself acts as a solar collector. A 26 in. diameter, 13 hp fan pulls the warm air from the walkway and pushes the air under the drying floor and up through the corn to be exhausted at the top of the grain bin. After the corn is dried to 18 percent moisture (wb) it is moved to another bin for completion of drying and storage and another 4 ft layer of corn is loaded into the drying bin. This procedure is repeated until the harvest and grain drying are complete. A propane burner downstream from the drying bin fan is used to add heat to the grain drying air until it reaches a temperature of 120°F.

COST

The materials and labor cost for the collector system, including the walkway to the grain bin used for drying, was $10,385.55 for 932 ft^2 or $11.14 per ft^2 of collector area. This can also be calculated as $207.71 per sow space. On this basis, had the collector been integrated into the unit at the time of construction it would have represented approximately 15 percent of the total construction cost. These costs are in 1979 dollars. No interest or opportunity costs are included in the figures.

PERFORMANCE

A. Thermal

The main purpose for the solar collector system was to provide preheating of the winter ventilation air. Additional anticipated uses were preheating air for grain drying and cooling ventilation air for the farrowing house during the summer. All of these uses for the solar collector system have been realized.

Typical data from the winter ventilation air preheating mode of operation for the solar collector system are presented in Figure 7. Outdoor ambient temperatures during that time period ranged from a high of 38°F to a low of -4°F. Temperatures at the collector outlet point ranged

from 57 to 16°F during this same time period for an average temperature rise of 16°F.

The benefit of having heat storage as part of the collector system is evident in the continued ventilation air temperature increase through the night. In fact, a larger quantity of heat was transferred to the ventilation air during the nights than during the days. Thus, solar energy collected during the day was stored for subsequent release to the ventilation air. This delayed release of collected heat is highly desirable since heating needs are greater overnight. The result is increased utilization of collected solar energy.

Data from the grain drying mode of solar collector system operation are presented in Figure 8. Interpretation of these data and attribution of performance characteristics to specific parts of the system are complicated by some confounding features built into the system. One of these confounding factors is that air can enter the grain drying system at a number of points between the air inlet to the collector and the air inlet to the fan. Air enters along the walkway because the gaps between the ridges of the corrugated glazing and the walkway framing members are open. (Except during grain drying, this is desirable for odor and temperature control within the walkway, especially during warm weather). Additional air infiltration can occur between joints in the walkway and the duct leading to the fan inlet.

Besides this air infiltration, solar radiation can be collected by the vertical collector and also by the walkway. Yet, while the walkway can serve as a solar energy collector, it can also serve as an energy dissipator because the glazing on the walkway has a low thermal resistance, or R value, and can conduct heat to the cold environment outside the walkway.

The sensing accuracy of the thermocouple used to monitor air temperature in the walkway/duct is also open to question since it is close to the walkway wall to minimize interference with animal and personnel movement between the farrowing-nursery and growing-finishing buildings. This thermocouple may be in a boundary layer of air near the wall that has a higher or lower temperature than the rest of the air moving through the walkway. The combination of these circumstances makes it difficult to reason through the "why's" of the performance data.

The data do allow a few conclusions to be reached, however. One conclusion is that the walkway serves as a collector. The walkway, on the east side of the building and available for collection of morning solar radiation, experiences large and rapid temperature increases (Figure 8) as would be expected of a solar collector with no storage medium. In the early afternoon the building shades this part of the walkway resulting in early daily temperature declines. The northern part of the walkway at the air inlet to the grain bin fan is not shaded by the building and its temperature peak comes an average of two hours later in the day.

The south-facing block wall collector shows the characteristics of a collector with storage in that the temperature at the collector outlet does not increase or drop off as quickly nor exhibit the temperature extremes noted in the walkway. The temperature of the air leaving the collector is the highest temperature in the system during the nighttime hours which demonstrates that the storage in the vertical solar wall is providing heat to the system overnight.

A computer program was used to average the temperature rise between the inlet to the grain drying fan and the outdoor ambient temperature. The program was also used to average the outdoor ambient temperature for the grain drying season of October 14 through November 13, 1981. The average temperature rise for this time period was 4F° with an average outdoor ambient temperature of 36°F.

The use of the propane burner to maintain a "constant" temperature of air entering the bin results in the solar collector having minimal effect on actual drying time. The benefit of the collector is to increase the temperature of air entering the fan thereby reducing the quantity of propane necessary to achieve the desired drying bin air input temperature of 120°F.

The solar collector actually performed no net cooling of summer ventilation air. Instead it provided a moderating effect to lower the high daytime air temperatures and raise the cooler nighttime temperatures (See Figures 9 and 10). During August of 1980 the daytime cooling total was 4.3×10^6 Btu, while the nighttime heating total was 9.6×10^6 Btu. In August of 1981 the daytime cooling total was 1.2×10^6 Btu, while the nighttime heating total was 1.3×10^6 Btu. Based on performance of other similar systems (e.g., Project NE-4) covering the collector probably will not allow a balancing of these two quantities despite no solar energy being added directly to the collector because of the conductive heat flow from the building to the collector and through the collector cover. However, the maintenance of higher indoor ambient temperatures through heating of the nighttime ventilation air could produce deleterious effects on the animals since relief from high daytime temperatures is minimized or eliminated. This factor must be very carefully considered when using this collector system in conjunction with housing for lactating or breeding age animals.

B. Economic

During the year of operation prior to construction of the solar collector, the farrowing building required 5866 gal of propane for the heating season (7189 F°·days). During the first year of operation following installation of the solar collector, propane usage in the farrowing building was 3900 gal for the heating season with a load of 5526 F°·days. This converts to a savings of 0.11 gal/F°·day or $0.062/F°·day (propane at $0.56/gal). These fuel requirements are based on information from fuel delivery tickets.

Using the AGNET computer model DRY CROSSFLOW, 19.5 hours of drying time was required to dry a batch (1970 bu) of corn. This required

1.21 MBtu of energy or 15.1 gal of propane energy equivalent. With propane costs at $0.56/gal and 50,000 bu of corn harvested in 1981, the estimated cost of the energy provided by the collector during the grain drying season was $215. This converts to $0.0043 per bu.

With an average annual farrowing house heating load of 5973 F°·days and a grain drying load of 50,000 bushels, the use of the solar collector can save approximately $585 per year. Since no summer ventilation cooling would be used if the solar collector did not exist and no clear cut benefits were derived from its use in this mode, no energy savings can be attributed to this aspect of the solar collector system. If benefits in terms of better animal production can be clearly shown to exist from such cooling, the dollar value of those benefits should be included in the annual savings from the solar collector.

With the collector cost of $10,385.55 and an annual savings of $585, the simple payback period is calculated to be nearly 18 years. Replacement of the glazing may be necessary every five years. Even with inflation, increasing energy costs, interest and opportunity costs used with the time-value-of-money approach to estimate the life cycle costs for this collector, the design is considered to be a non-economical investment. However, the availability of government cost-sharing money to reduce the operator's investment could result in an economical system for the producer while reducing the use of fossil fuels.

C. Problems

Adding the collector under an existing eave was difficult. Extending the eave to provide full cover for the collector was also a problem.

Dust accumulating on the glazing layers is slowly decreasing the transmission of solar energy to the absorber. No easy way exists to clean the inner glazing.

Measurement of airflow through the collector was attempted with a manometer to determine the static pressure against which the fans were operating and with a hot wire anemometer. No consistency was attainable, and in many cases, the air velocity was so low (less than 200 fpm) that accuracy of the instruments was questionable.

COMMENTARY

A. Construction Suggestions

1) Be sure to seal the collector carefully. This will help ensure proper airflow through the collector. Air leaks have appreciable adverse effects on collector performance. Joints are much more easily sealed during construction than as a repair operation. Use only high quality, long-life caulking materials. Clear silicone caulk is recommended.

2) All air inlets to the collector should be covered with 1/2 x 1/2 in. wire mesh screening to prevent birds from entering the solar system and the building.

3) Provide enough overhang so rain and snow do not drip or blow into the collector inlet. Do not make the overhang wider than necessary since doing so could result in shading part of the collector.

4) When painting blocks, be sure to protect them from rain. Failure to do so results in leaching of minerals from the concrete and formation of a white deposit on the outside of the paint.

B. Suggested Modifications

1) Other blocks may be substituted for the FHA blocks. When substituting other blocks be sure to provide proper spacing between the blocks for airflow. Allow between 3 and 5 ft^2 of open area in the block wall per 1000 cfm of ventilation air.

2) The FHA blocks, even when filled with sand to achieve the equivalent mass of an 8 x 8 x 16 in. solid block, do not meet the generally recommended storage mass to collector area ratio. Consideration should be given to alternate designs which provide 2 ft^3 of storage mass per ft^2 of collector.

3) The collector design described in this report allows all winter and spring/fall ventilation air to be pulled through the collector. It may be desirable to warm only the winter ventilation air. This can be accomplished by installing motorized shutters in the ends of the collector. These shutters should be wired in parallel with the spring/fall fan so they open whenever the spring/fall fan operates. This will occur when the building temperature is high enough so heating is not required but when spring/fall ventilation rates are necessary to effect some temperature control. Air from the outside is pulled through the shutters into the plenum behind the blocks. From there the air is pulled into the building for ventilation. Under this operational mode a very minimal airflow will occur through the collector. The collector can then "stagnate" with very low airflow and solar radiation can be stored in the blocks until heat is needed during cool nights or days. This arrangement reduces ventilation loads and increases the utilization of solar energy. Thus, overall system efficiency is improved.

4) Solar collectors will not be helpful for all grain drying operations and in some instances can actually be detrimental. All components of the grain drying operation must be matched to avoid grain quality losses and to achieve reasonable operational efficiencies.

5) For further information on the application of solar energy in your state contact your county Extension agent or Extension Agricultural Engineer at your Land-Grant University.

PROJECT MANAGEMENT

Work on this project was performed by the University of Nebraska Department of Agricultural Engineering. Individuals directly involved were Gerald R. Bodman, P.E., Extension Agricultural Engineer--Livestock Systems (Project Manager) and Michael F. Kocher, Extension Assistant (Project Coordinator). Inputs from the Departments of Agricultural Economics and Animal Science are acknowledged.

Table 1. Winter ventilation preheating data for the farrowing house (Lay).

	1980			1981	
	OCT.	NOV.	DEC.	JAN.	NOV.
Total heat required, 10^6 Btu	0.30	21	22	30	7.8
Total heat supplied by solar, percent	100	80	60	66	100
Average indoor ambient temperature*, °F	62	59	48	52	58
Average outdoor ambient temperature, °F	44	21	15	14	32

*This thermocouple was located in the middle of the east farrowing room, about 5 ft above the floor (not in the pig zone). The control panel with the east farrowing room ventilation fan controls was also in this location.

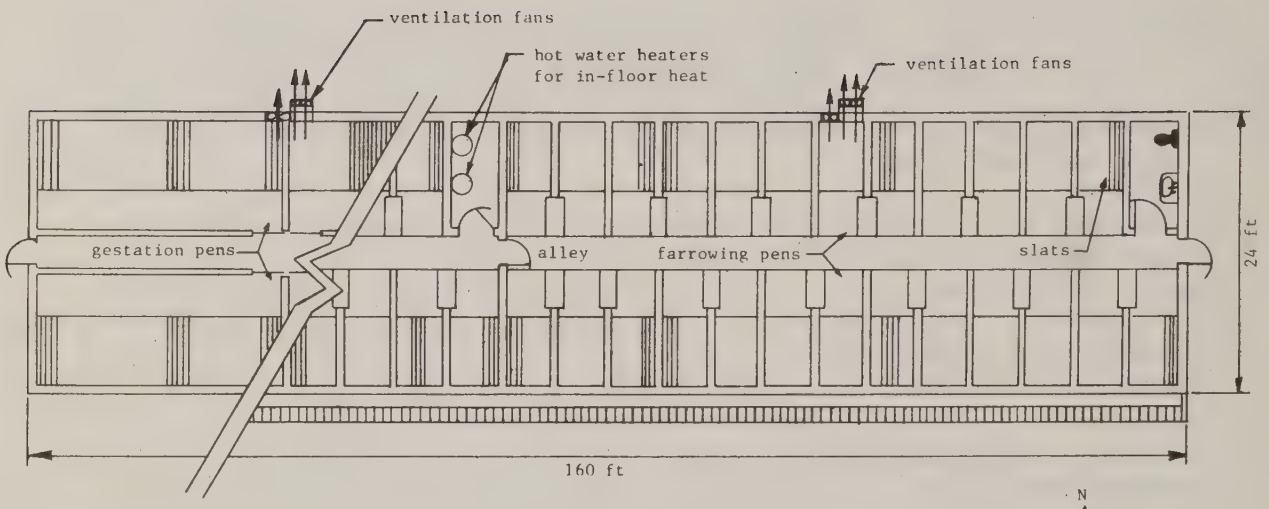


Figure 1. Floor plan for Merlyn Lay's farrowing-nursery facility. Gestation unit in west end of building.



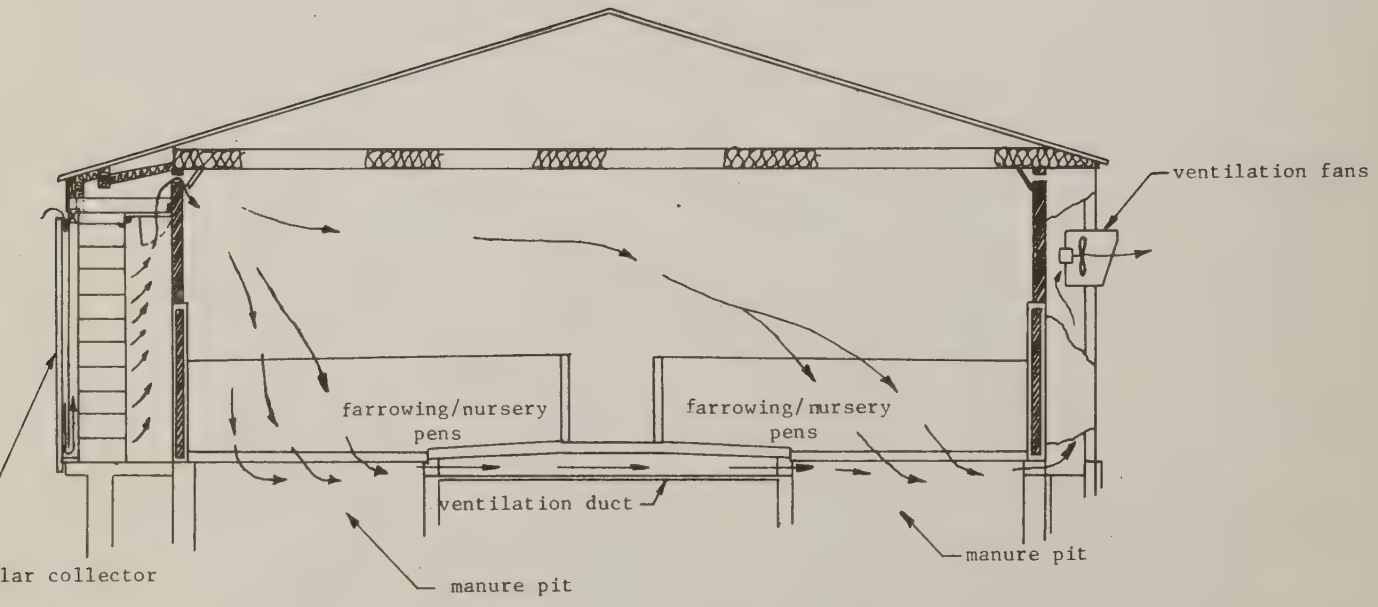


Figure 2. Building cross section schematic showing winter ventilation air movement (Lay). Minor details omitted for clarity.

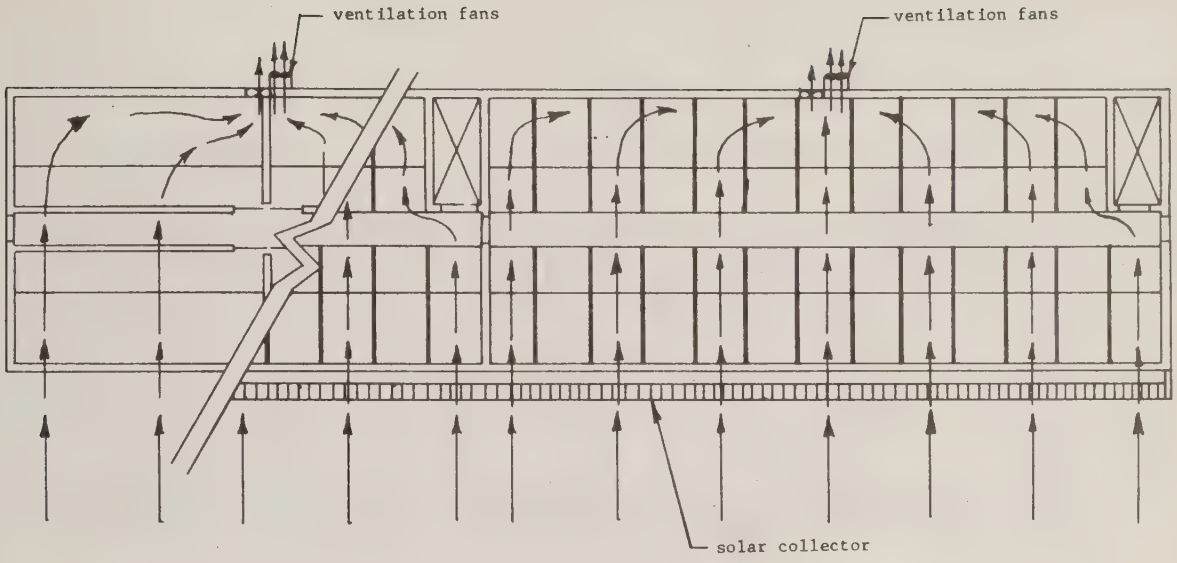


Figure 3. Floor plan schematic showing winter ventilation air movement (Lay). Minor details omitted for clarity.

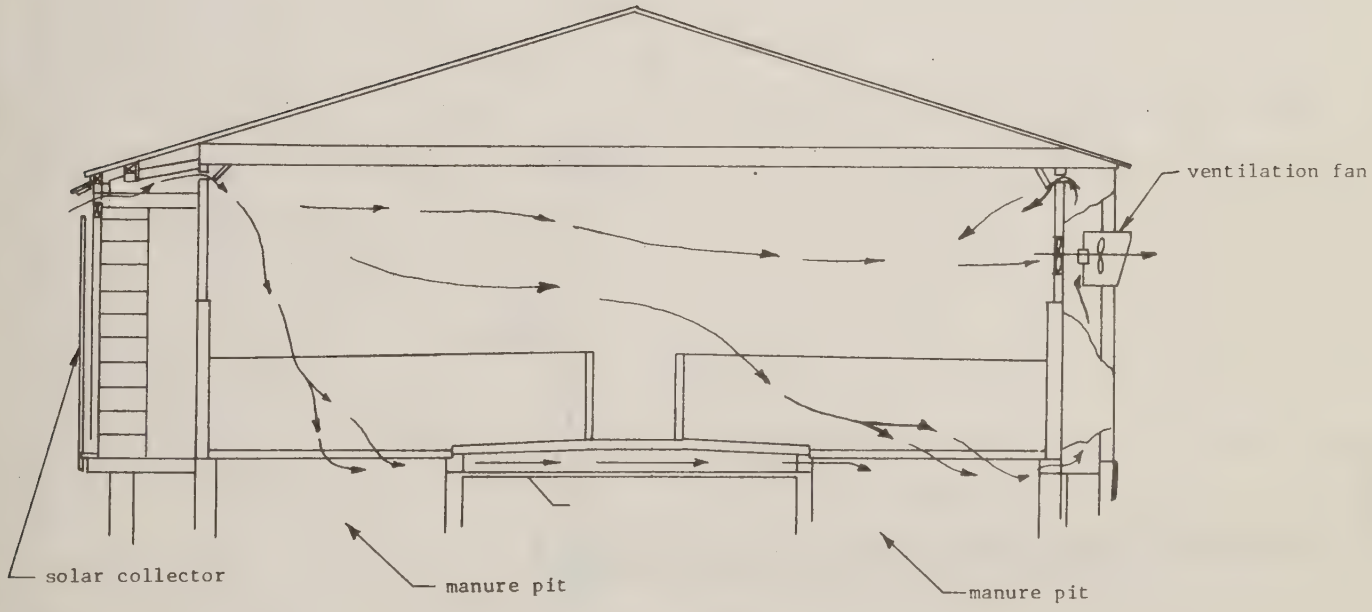


Figure 4. Building cross section schematic showing summer ventilation air movement (Lay). Minor details omitted for clarity.

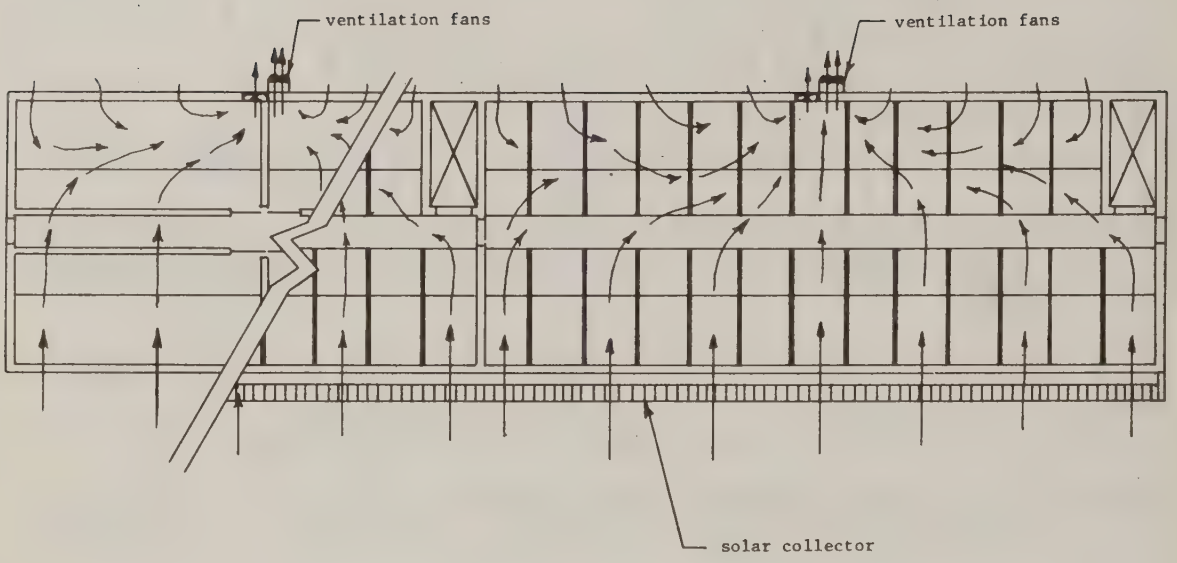


Figure 5. Floor plan schematic showing summer ventilation air movement (Lay). Minor details omitted for clarity.

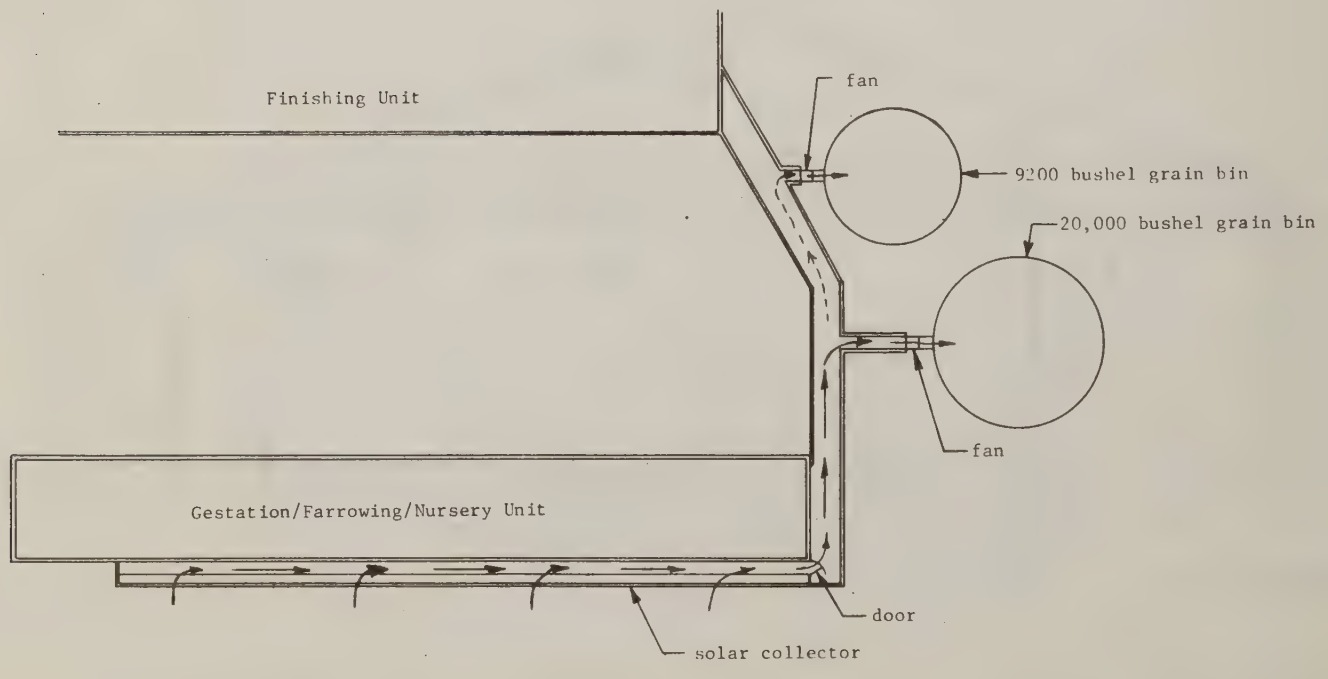


Figure 6. Site plan showing grain drying airflow paths (Lay). Details omitted for clarity.

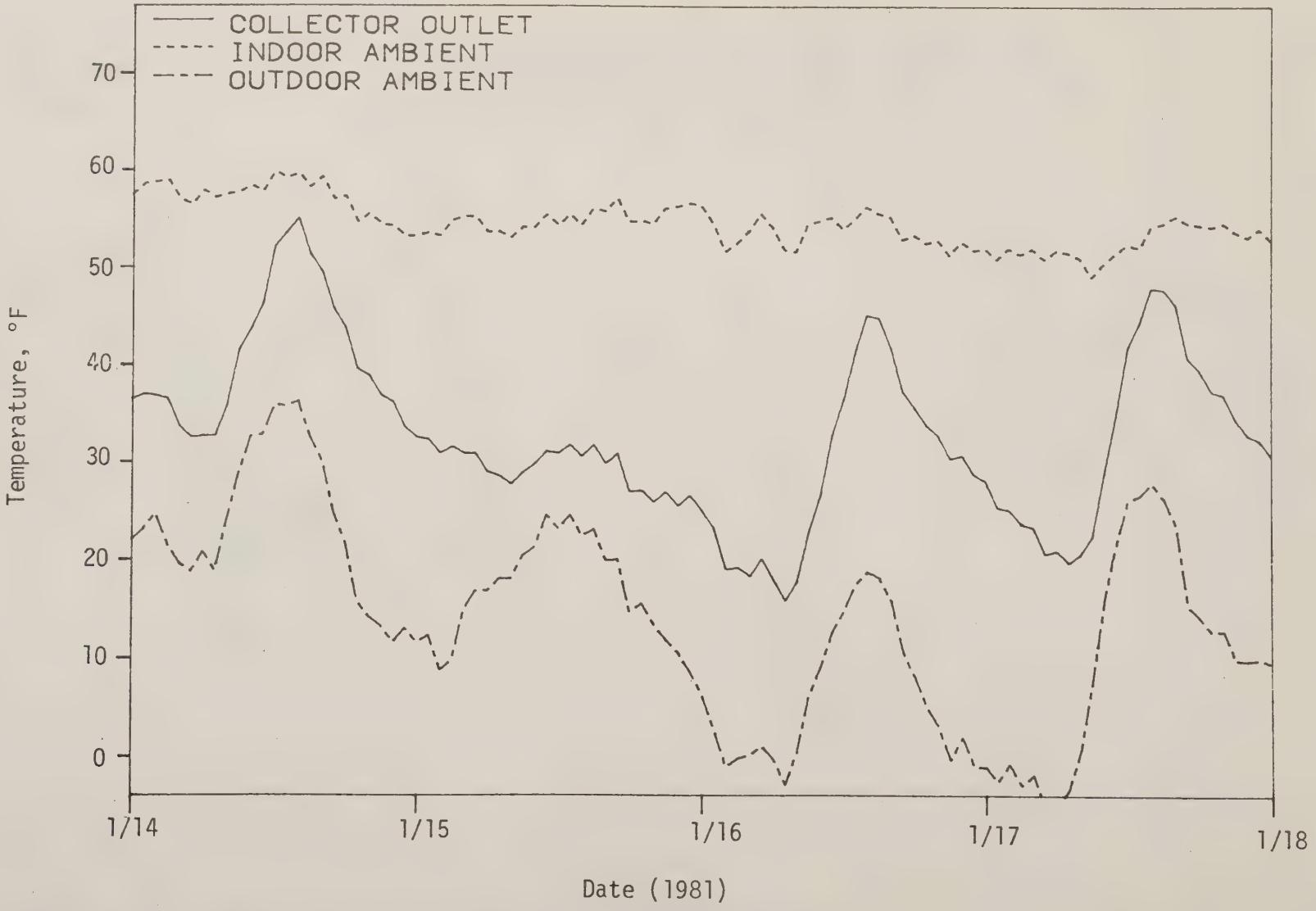


Figure 7. Farrowing house winter ventilation preheating temperatures with the vertical solar wall (Lay).

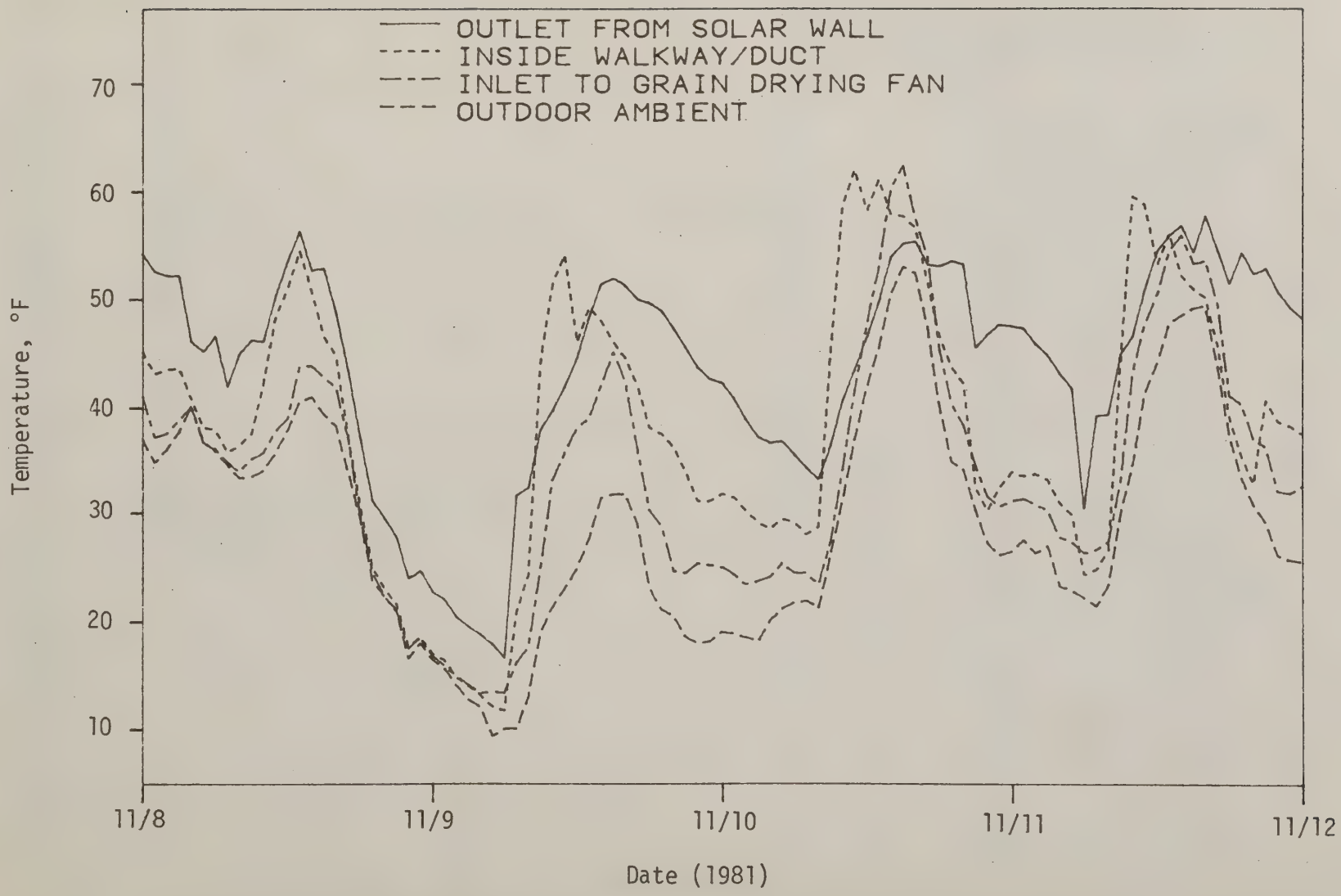


Figure 8. Grain drying air preheating with the vertical solar wall and walkway/duct (Lay).

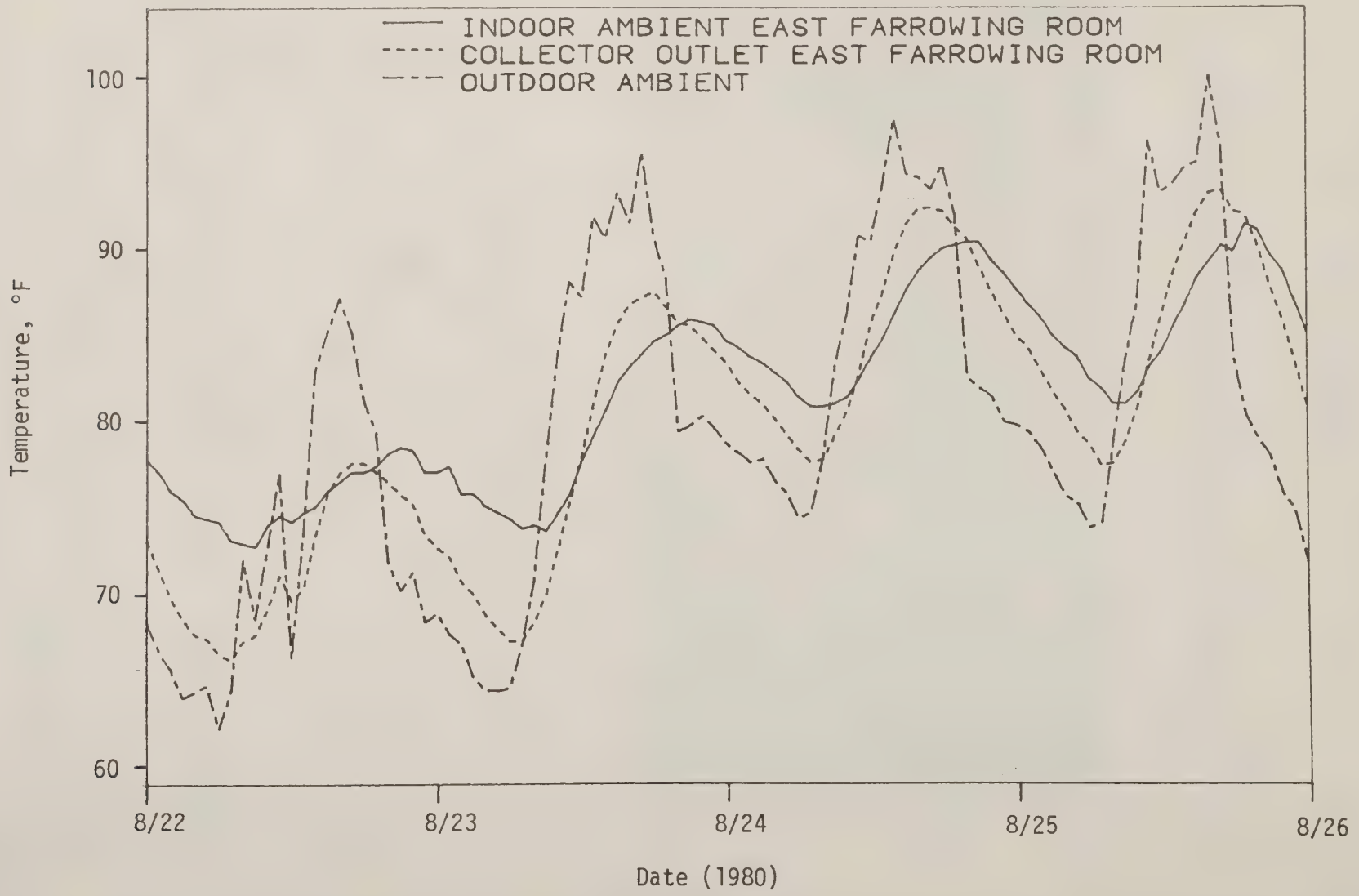


Figure 9. East farrowing room summer ventilation cooling temperatures with the vertical solar wall (Lay).

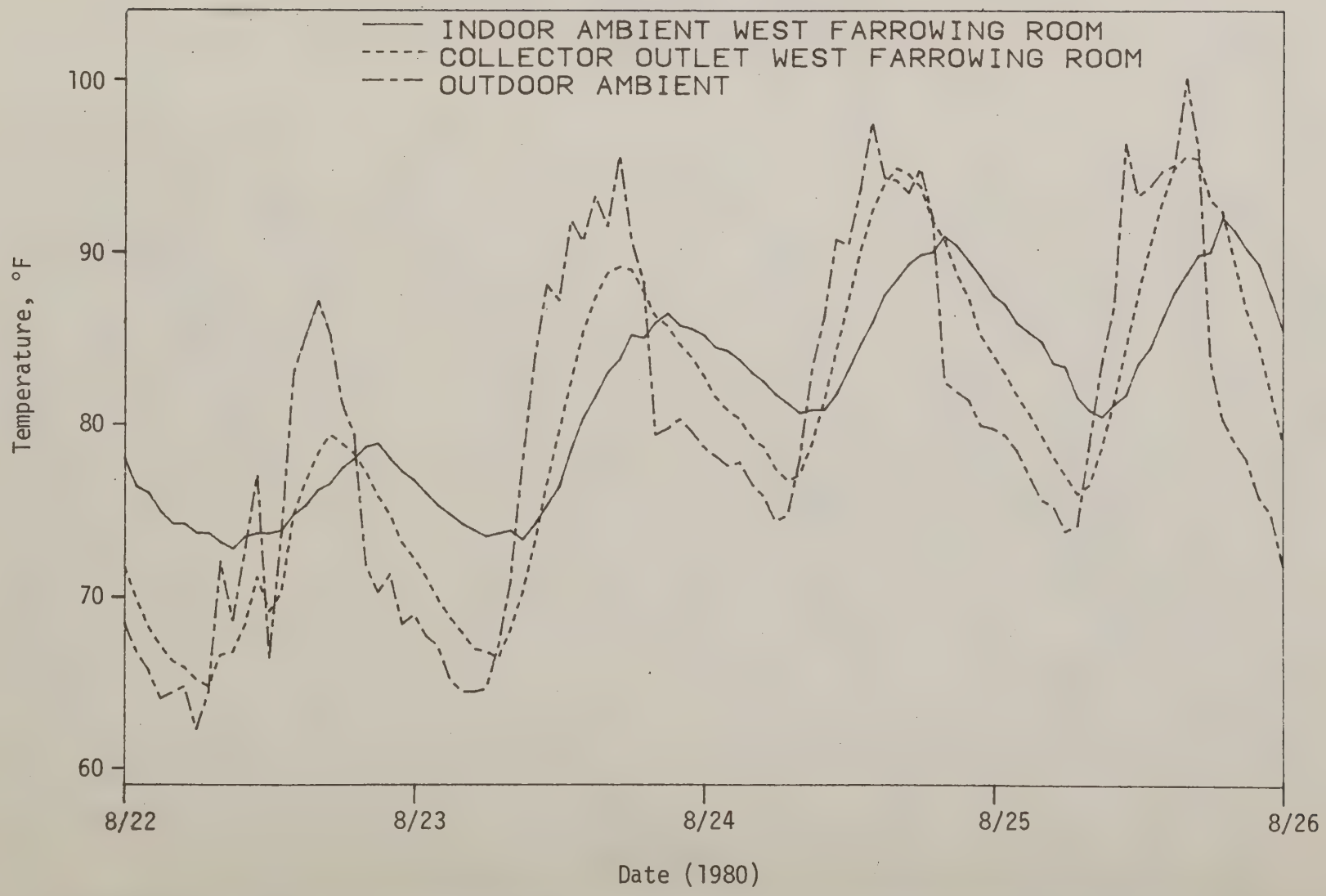


Figure 10. West farrowing room summer ventilation cooling temperatures with the vertical solar wall (Lay).

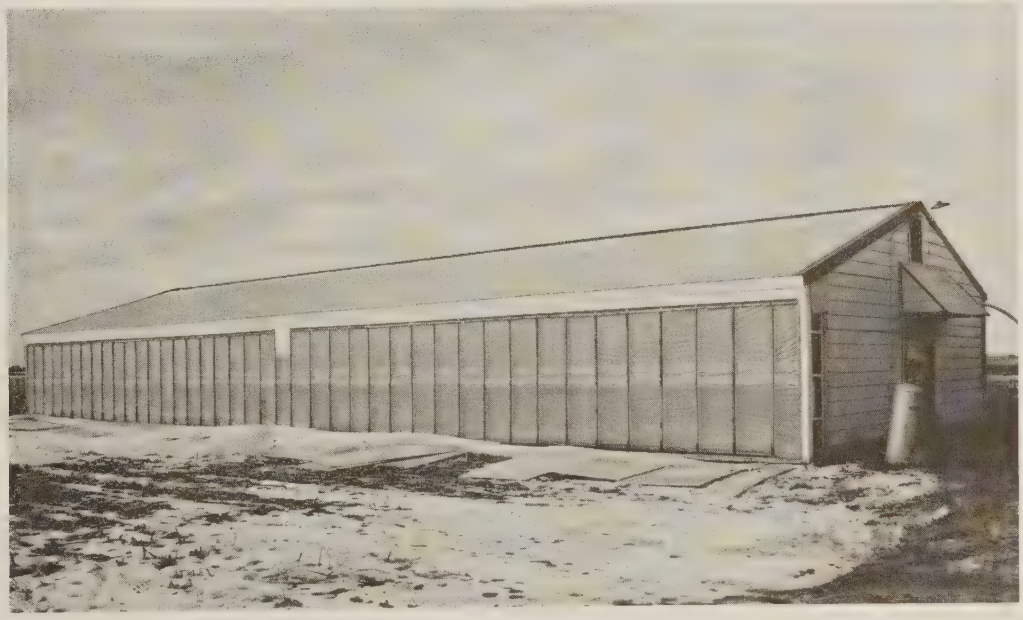
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COMBINATION SWINE FARROWING-NURSERY BUILDING WITH A VERTICAL SOLAR WALL

Craig Buescher
Deweese, NE

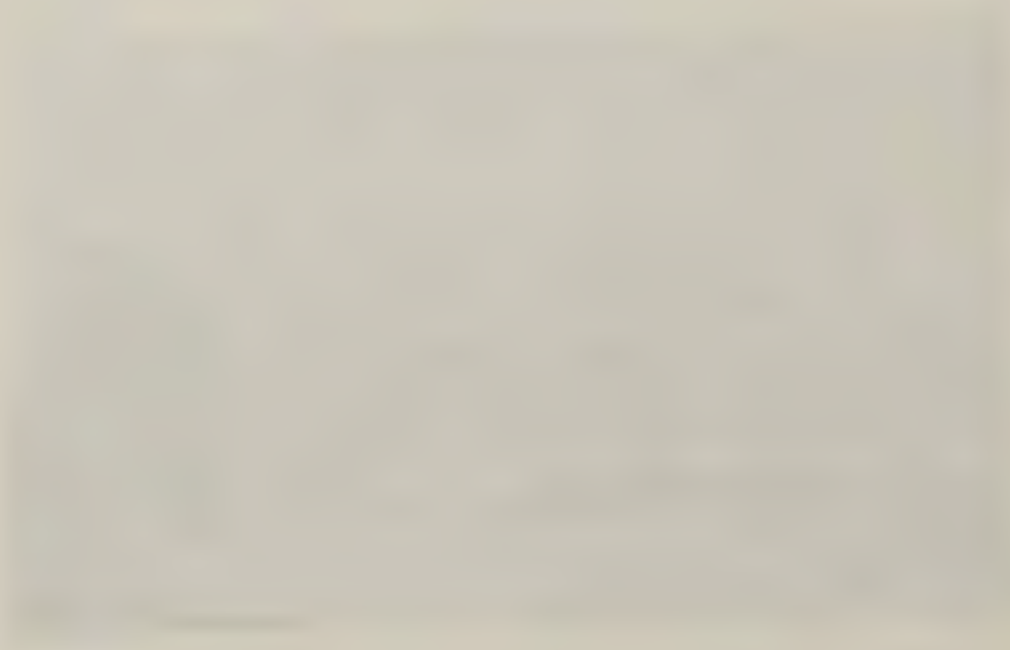
Demonstration Project
Solar Heating of On-Farm Livestock Structures
Project NE-4



12-sow farrowing-200 pig nursery building with solar collector for ventilation air preheating or cooling.

UNIVERSITY OF NEBRASKA-LINCOLN, COOPERATING WITH THE COUNTIES AND THE U.S. DEPARTMENT OF AGRICULTURE

The University of Nebraska-Lincoln The University of Nebraska Medical Center The University of Nebraska at Omaha



COMBINATION SWINE FARROWING-NURSERY BUILDING WITH A VERTICAL SOLAR WALL

Craig Buescher
Deweese, NE

THE FARM

Craig Buescher owns and operates the farm on which this demonstration facility is located. The farm (40°23'N, 98°10'W) is located in south central Nebraska's Clay County. Dryland crops include approximately 12 acres of alfalfa, 100 acres of wheat, 200 acres of sorghum and 35 acres of soybeans. Alfalfa and sorghum are grown on 12 and 100 acres of irrigated cropland, respectively. Livestock operations on the Buescher farm include a cow-calf herd of about 20 cows and a 70-sow farrow-to-finish operation. Annual swine production is approximately 1100 market-weight hogs. Craig also sells York and Landrace gilts as breeding stock. The swine facility that Craig had been using was destroyed by fire thus necessitating the construction of the new solar farrowing-nursery unit.

The Bueschers have cooperated with the University of Nebraska, the U.S. Department of Agriculture and the U.S. Department of Energy in designing, instrumenting, and monitoring this system. This report includes a description of the building, a description of the solar system and the cost of the solar system. Guidelines for construction of this system, some system performance results and suggested system modifications are also included.

GOALS

The design of the solar collector system was governed by the following objectives:

1) The solar collector system must be designed to allow the farmer or farm builder to construct the system with as much locally available material and equipment as is technologically and economically possible.

2) The system must be understandable and manageable by the farmer.

3) The system must be designed so the farmer can reasonably be expected to make any necessary repairs.

SYSTEM DESCRIPTION

A. The Farrowing-Nursery Facility

The farrowing-nursery facility has three basic areas. A 12 x 70 ft farrowing room exists side-by-side with a 12 x 70 ft nursery room. Across the end of those two rooms is a 12 x 24 ft work area, including an office, feed storage and a sow wash (See Figure 1). The building has a gable roof and is mechanically ventilated with two insulated ducts, one on each side of the wall dividing the two rooms, supplying fresh ventilation air and exhausting warm moist air (See Figures 2 and 3). The farrowing room has 12 crates above a flushing gutter (See Figure 4). The flushing device for the farrowing room is a tipping bucket. Auxiliary heat for the farrowing room is provided by heat lamps when the solar collector system cannot provide enough heat.

The 200-pig nursery room has twelve 5 ft x 9 ft-6 in. pens with fenceline feeders in the back portion of the pens. A 30 in. wide open flush gutter is located in the front of each pen (See Figure 4). This flush tank uses a dosing siphon to discharge the flush water. Auxiliary heat for the nursery room is provided by a vented unit heater.

B. The Solar Collector System

The 590 ft^2 solar collector is a concrete block wall with two Tedlar® glazing layers on the 82 ft long south side of the building. The collector system was constructed based on plans obtained from Kansas State University. The block wall is not of typical construction but consists of 8 x 8 x 16 in. (nominal) solid concrete blocks placed so the long dimension is perpendicular to the building. A 9 in. space between the block wall and the south wall of the farrowing room forms a plenum for airflow behind the block wall.

The blocks in the collector are dry stacked (no mortar) with 3/16 in. vertical gaps between adjacent blocks. These gaps allow airflow through the block wall. The south side of the block wall is painted black to increase the absorption of solar energy allowing the blocks to act both as absorber surface and heat storage material (1.3 ft^3 of thermal storage mass per ft^2 of collector).

The slots and gaps in the collector glazings and blocks are designed so ventilation air enters the collector between the glazings, travels across the black surface of the block wall and filters through the gaps between the blocks into the 9 in. plenum behind the blocks. Once in the plenum the air travels down the length of the plenum (towards the west) to the cross duct that conveys air to the supply side of the divided ventilation ducts. The ventilation fans exhausting moisture, gases and odors continually pull exhaust air from the building into the exhaust side of the divided ducts, and discharge it out of the building. This creates a slight vacuum inside the building which draws the fresh air from the supply side of the divided ventilation ducts into the building (See Figures 2 and 3). In this way the building ventilation fans provide the power to move the air through the collector instead of having a separate fan perform this function.

The system is constructed so the collector can preheat winter ventilation air (2.3 cfm per ft^2 of collector) for both the nursery and farrowing rooms (See Figure 2). During the summer, ventilation air for the nursery is pulled directly from outdoors into the nursery room through a duct located in the work area (See Figure 5). Ventilation air for the farrowing room is pulled through the collector year-round. During the summer the collector is covered to reduce solar radiation on the blocks and to provide cooling for the farrowing room ventilation air. On summer nights a fan in the middle of the collector is turned on to exhaust air from the plenum to the outdoors (See Figure 6). This increases the amount of cool nighttime airflow through the blocks, thus increasing the cooling of the blocks to provide additional cooling capacity during the following day. During summer days this fan does not operate and only the ventilation fans in the farrowing room pull air through the collector, thereby cooling ventilation air before it is introduced into the farrowing room (See Figure 5).

COST

The cost for the materials and labor for the collector system was $7,601.57 for 590 ft^2 or $12.88 per ft^2 of collector area. These costs are in 1981 dollars. The materials and labor cost for the building was $30,000. The materials and labor cost for the solar collector system added 25 percent to the building cost.

PERFORMANCE

A. Thermal

The vertical solar wall has been used successfully to preheat winter ventilation air for the farrowing and nursery rooms since October 1981. During a 10 day period in January 1982 the building required 6.48×10^6 Btu of supplemental heat. This heat requirement was calculated from the "best estimate" ventilation rate, building heat loss factors, and the temperature differences between air inside the farrowing and nursery rooms, and air outside the building. The solar collector provided approximately 54 percent (3.49×10^6 Btu) of this load, as calculated from the temperature rise of the air and a "best estimate" of the airflow rate through the collector. During these 10 days the average indoor temperature for both rooms was 71°F while the average outdoor temperature was 24°F (range was 1 to 41°F).

For 16 days in February 1982 the building required 16.5×10^6 Btu of supplemental heat. Approximately 45 percent of this quantity (7.5×10^6 Btu) was provided by the solar collector. The average indoor and outdoor temperatures were 69°F and 14°F, respectively. The range of outdoor temperatures was -8 to 40°F.

Examples of typical outdoor, collector outlet, and indoor air temperatures for the farrowing and nursery rooms are presented in Figures 7 and 8, respectively. The temperature of the air at the collector outlet

remained higher than the temperature of the air entering the collector, especially at night. This demonstrated the effect of the concrete blocks as heat storage. The storage allowed a portion of the solar heat gathered during the day to be stored for release during the night. The storage of solar heat was also demonstrated in the time lag between the rapid rise in outdoor air temperature and the increase in temperature of the air leaving the collector.

The cooperator has used the solar collector to "cool" summer ventilation air for the farrowing room. Data collected for 23 days in July of 1981 showed that the collector provided 41.8 x 10^6 Btu of heating during the nighttime and 31.7 x 10^6 Btu of cooling during the daytime for a net heating gain of 10.1 x 10^6 Btu. Despite the covering of the collector and the use of additional energy to operate the cooling fan the net effect of passing summer ventilation air for the farrowing room through the collector was to add heat to the farrowing room. However, the collector did have a temperature moderating effect on ventilation air entering the farrowing room. The temperature of the air entering the farrowing room was lower than the daytime outdoor air temperature and higher than the nighttime outdoor air temperature (See Figure 9). The data did not allow a complete evaluation of possible benefits of this moderating effect from an animal performance standpoint. Research to date has not fully addressed the influence on sow productivity (milk production and breed-back efficiency) of a moderated temperature range versus higher daytime and lower nighttime temperatures.

While the summer ventilation air for the farrowing room passed through the solar collector a separate air inlet allowed outside air to be drawn directly into the nursery. Air temperature in the nursery remained at reasonable levels for these pigs, as can be seen in Figure 10. Pig performance was judged to be quite satisfactory though data, per se, were not available.

B. Economic

Extrapolating from the winter heating data, the solar collector should save an average of 45 percent of the annual heating load for the building. Using an average annual heating load of 5973 degree days requiring 149 x 10^6 Btu of heat the solar collector should save 67.0 x 10^6 Btu or 729 gal of propane.

With a propane price of $0.56 per gal, the estimated annual fuel savings would be $408. The collector cost of $7,601 divided by $408 savings per year yields a simple payback period of nearly 19 years. This includes no economic returns from the "cooling" aspect of the solar collector system, and makes none of the assumptions required for the time-value-of-money approach for life-cycle cost analysis. The omission of economic benefits from "cooling" are considered valid since the net effect was really heating. Further, elimination of the collector-cooling system would not have necessitated incorporation of a separate cooling system.

The solar collector life is expected to be 20 years, except for the glazing material. Current estimates of glazing life are 5 to 10 years. Without subsidy, this collector cannot be considered cost-effective.

C. Maintenance

Periodic maintenance of the ventilation system (including the fan for summer cooling of the blocks) will keep the majority of the solar collector system in good condition. Glazings should be checked periodically for damage, especially after storms. Check the collector system joints for cracks that need to be caulked. Check the air inlet to the collector periodically to be sure they are free from dust. Wash the outer glazing of the solar collector when it becomes dirty. Maintenance of the remainder of the collector system will be similar to maintenance of the exterior of the building.

COMMENTARY

A. Construction Suggestions

1) Glazing materials for the collector should be chosen to withstand ultraviolet light degradation and to have good solar energy transmittance characteristics.

2) Be sure to seal the collector carefully except where airflow is desired. This will ensure proper airflow through the collector. Air leaks at the wrong places can greatly affect collector performance. It is much easier to seal joints during construction than to repair air leaks. Use only high quality, long life caulking materials. Clear silicone caulk is recommended.

3) All air inlets to the collector should be covered with 1/2 x 1/2 in. wire screening to prevent birds from entering the solar system and the building.

4) The nursery ventilation air inlet for summer should be covered with 1/2 x 1/2 in. wire screening and a hood to prevent birds and rain from entering the ventilation duct.

5) Provide enough overhang so rain and snow do not blow into the collector inlet, but don't put in too much overhang or shading of the collector will result.

6) Install all fans and shutters in a manner which allows access and/or removal for servicing and repairs.

B. Operation suggestions

1) Sometime during the fall (management decision as to when) the divider panel that goes into the divided ducts should be removed. This is the duct divider panel shown in Figures 5 and 6. Remove the covers from the face of the solar collector at this time.

2) When the duct divider panel is removed (See preceding point) the nursery ventilation air inlet for summer ventilation should be covered with an insulated door to reduce heat loss in this location and to prevent introduction of large quantities of cold infiltration air into the building.

3) Sometime during the spring (management decision as to when) the insulated door should be removed from the nursery ventilation air inlet. The duct divider panel should be installed to divide the ducts for independent summer ventilation. Cover the collector at this time.

C. Suggested Modifications

1) The 8 x 8 x 16 in. solid concrete blocks do not have the full storage mass of 2 ft^3 per ft^2 of collector area as generally recommended. Other blocks may be substituted for the solid concrete blocks. The "trick" to substituting other blocks is to provide proper spacing between the blocks for airflow. Allow between 3 and 5 ft^2 of open area in the block wall per 1,000 cfm ventilation air (maximum airflow rate through collector is normally summer ventilation rate).

2) The building design described in this report requires the central duct work for good ventilation. It is easier to accommodate proper ventilation without duct work by using end-to-end room construction as opposed to side-by-side. This eliminates the need for the divided central ducts and allows use of over-the-wall slot inlets for ventilation and ventilation fans centered in a group along the north wall of the building. In all cases, fans must be protected from direct discharge into the wind.

3) For further information on the application of solar energy in your state contact your county Extension agent or Extension Agricultural Engineer at your Land-Grant University.

PROJECT MANAGEMENT

Work on this project was performed by the University of Nebraska Department of Agricultural Engineering. Individuals directly involved were Gerald R. Bodman, P.E., Extension Agricultural Engineer--Livestock Systems (Project Manager) and Michael F. Kocher, Extension Assistant (Project Coordinator). Inputs from the Departments of Agricultural Economics and Animal Science are acknowledged.

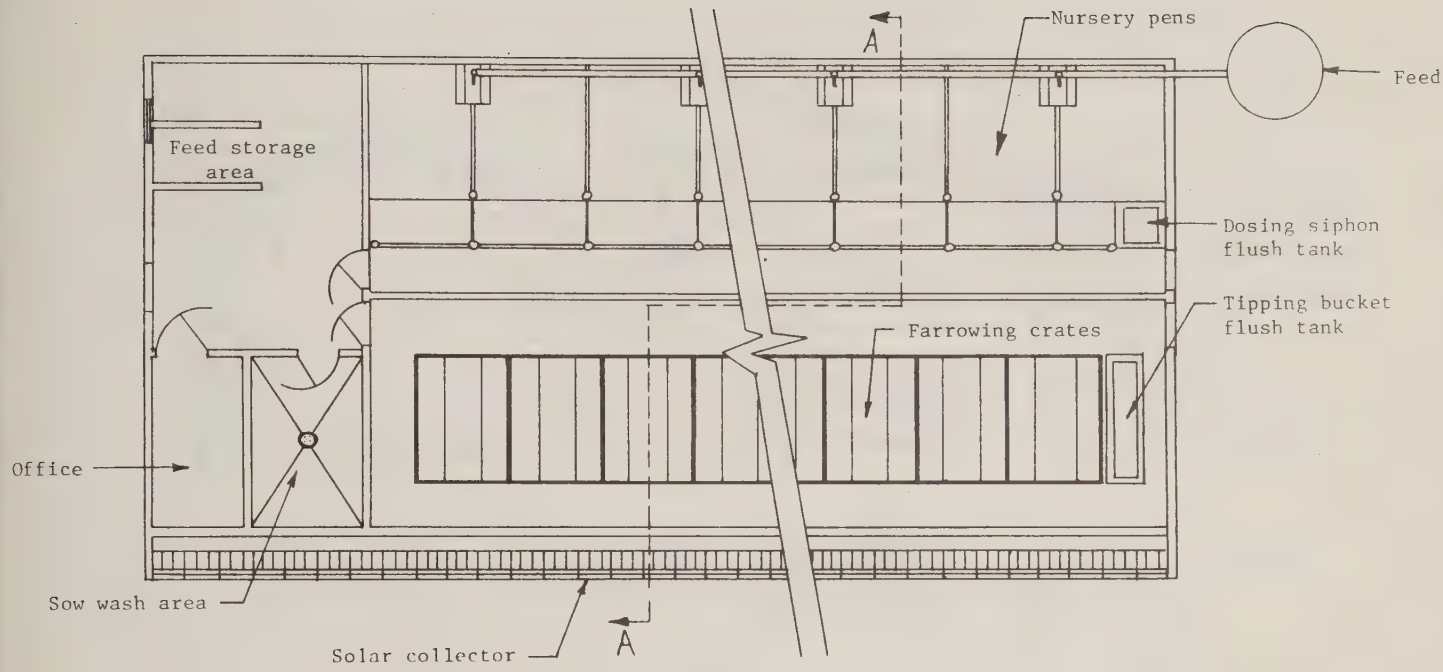


Figure 1. Floor plan of the 12-sow farrowing/200-pig nursery building (Buescher). Details omitted for clarity.

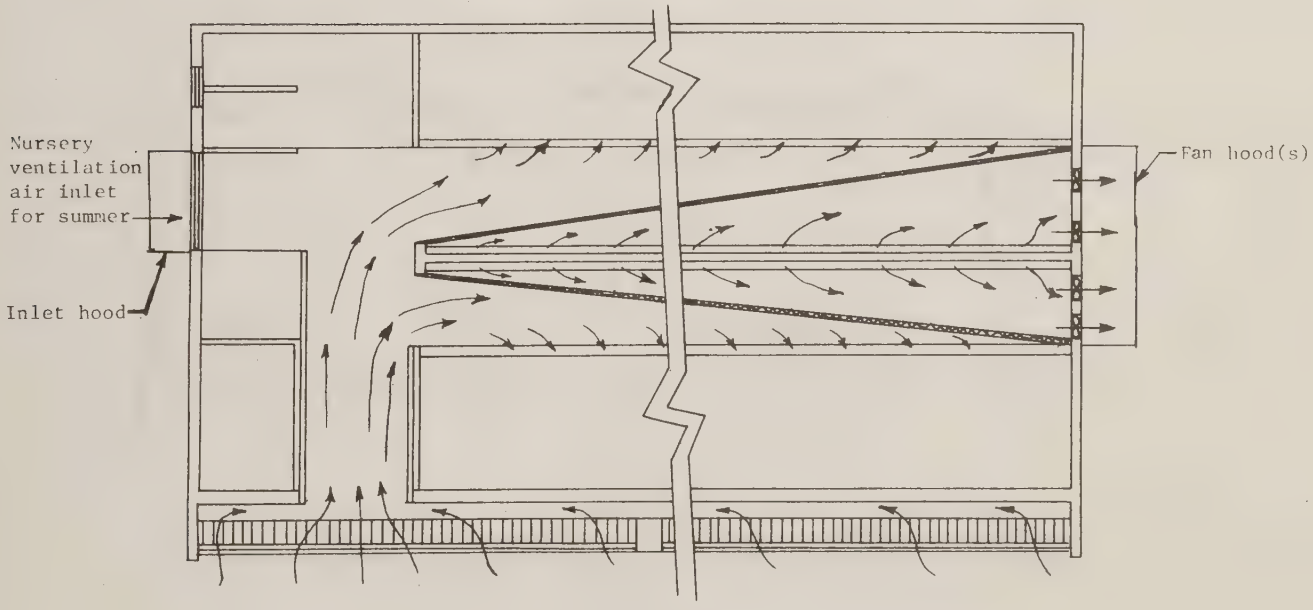


Figure 2. Floor plan schematic of winter ventilation airflow in the collector and ventilation ducts (Buescher). Details omitted for clarity.

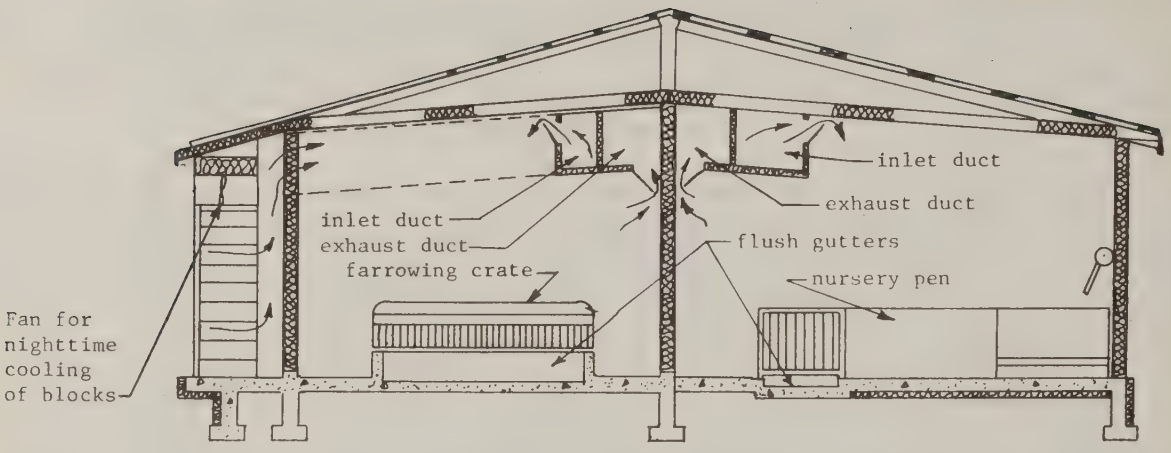


Figure 3. Cross section schematic of ventilation airflow (Buescher). Details omitted for clarity.

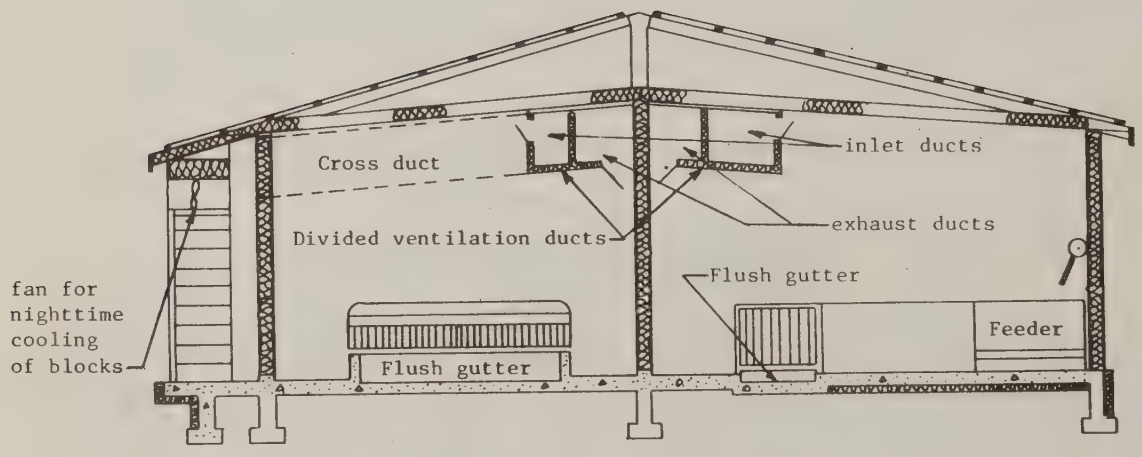


Figure 4. Partial cross section of the building (Buescher). Details omitted for clarity.

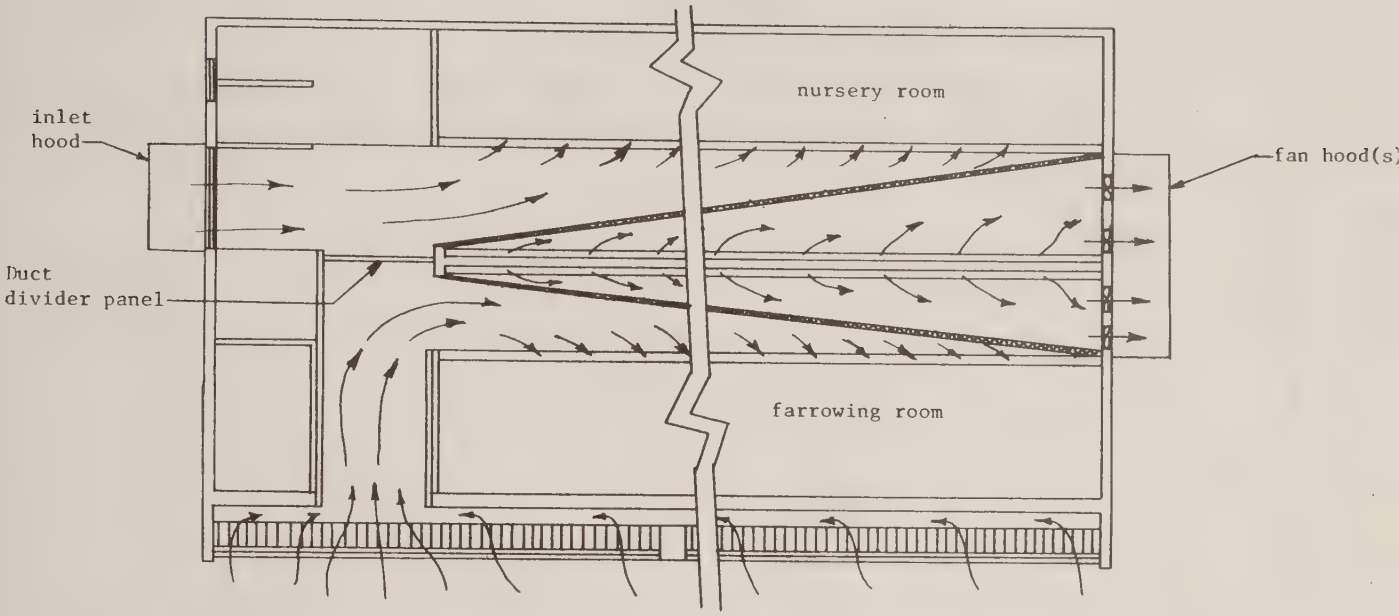


Figure 5. Floor plan schematic of summer daytime ventilation airflow in the collector and ventilation ducts (Buescher). Details omitted for clarity.

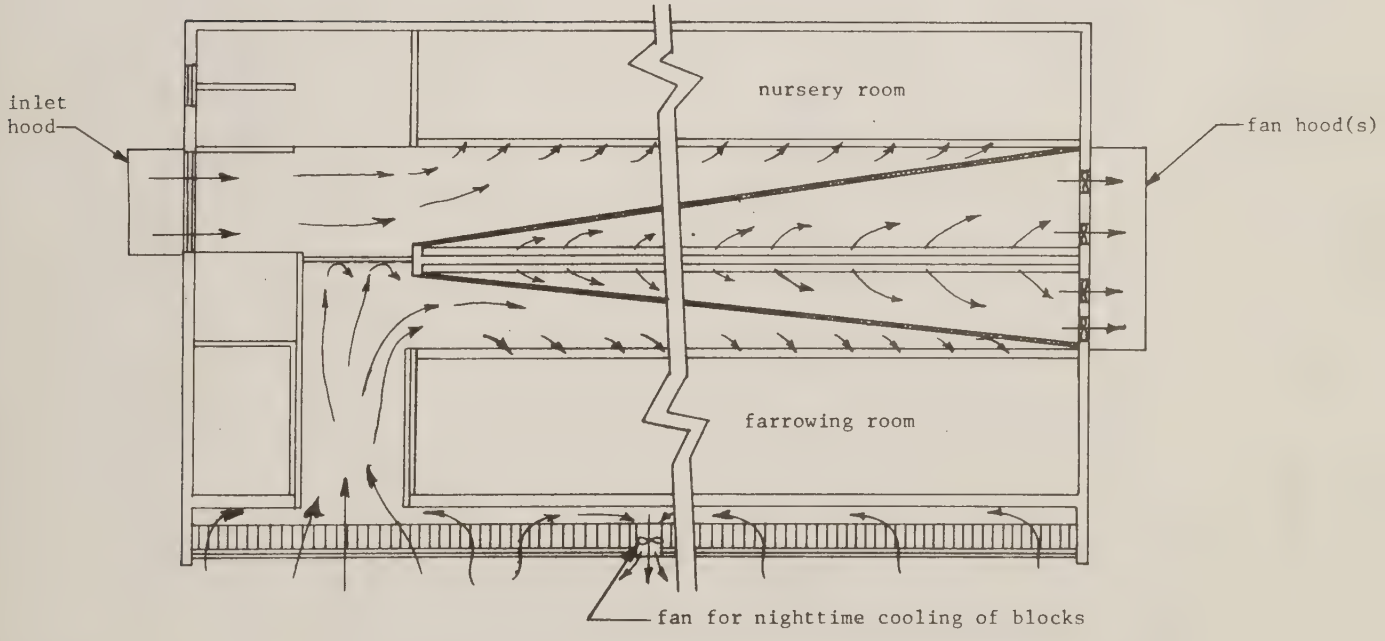


Figure 6. Floor plan schematic of summer nighttime ventilation airflow through the collector and ventilation ducts (Buescher). Details omitted for clarity.

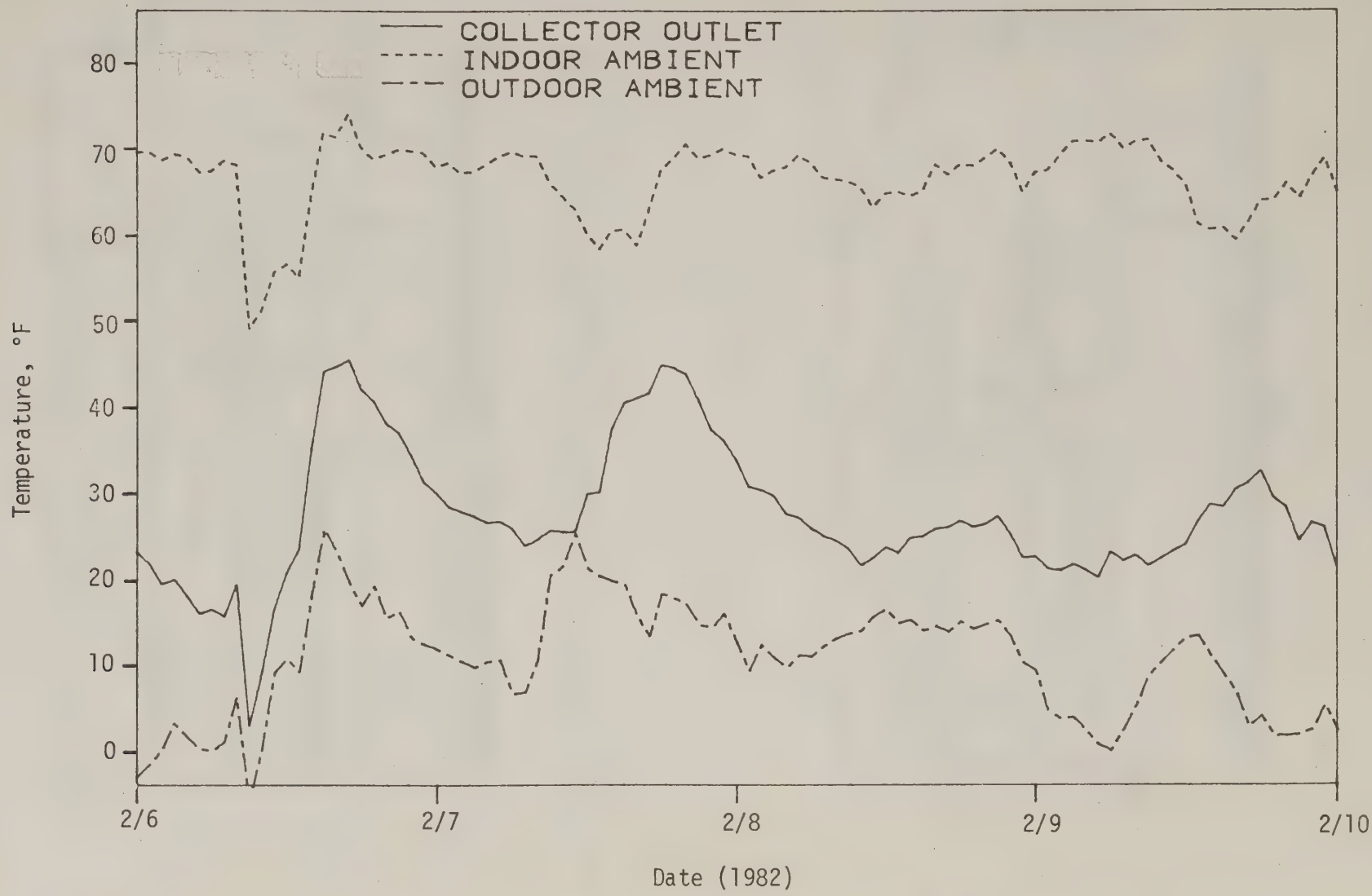


Figure 7. Farrowing room winter ventilation air preheating with a vertical solar wall (Buescher).

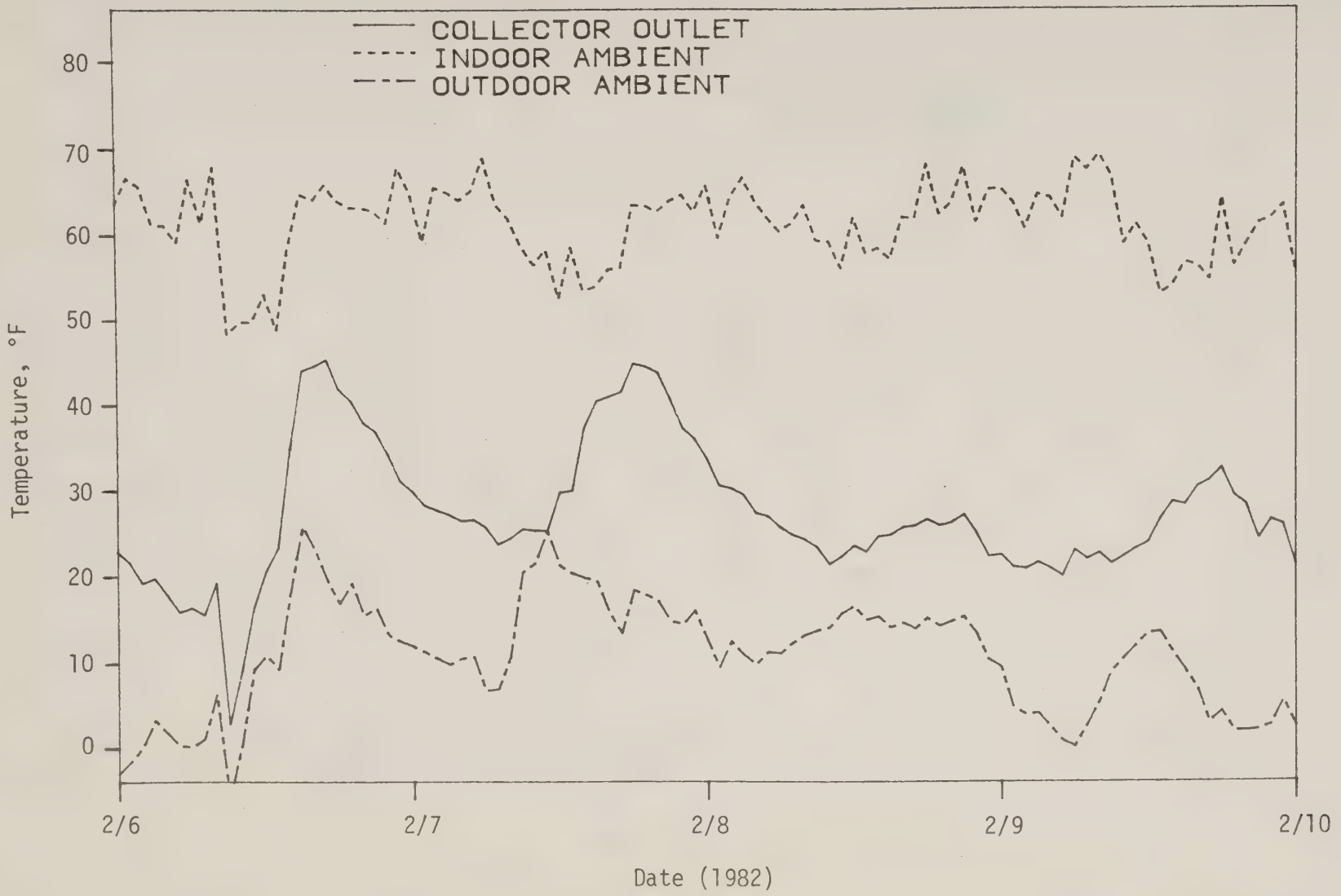


Figure 8. Nursery room winter ventilation air preheating with a vertical solar wall (Buescher).

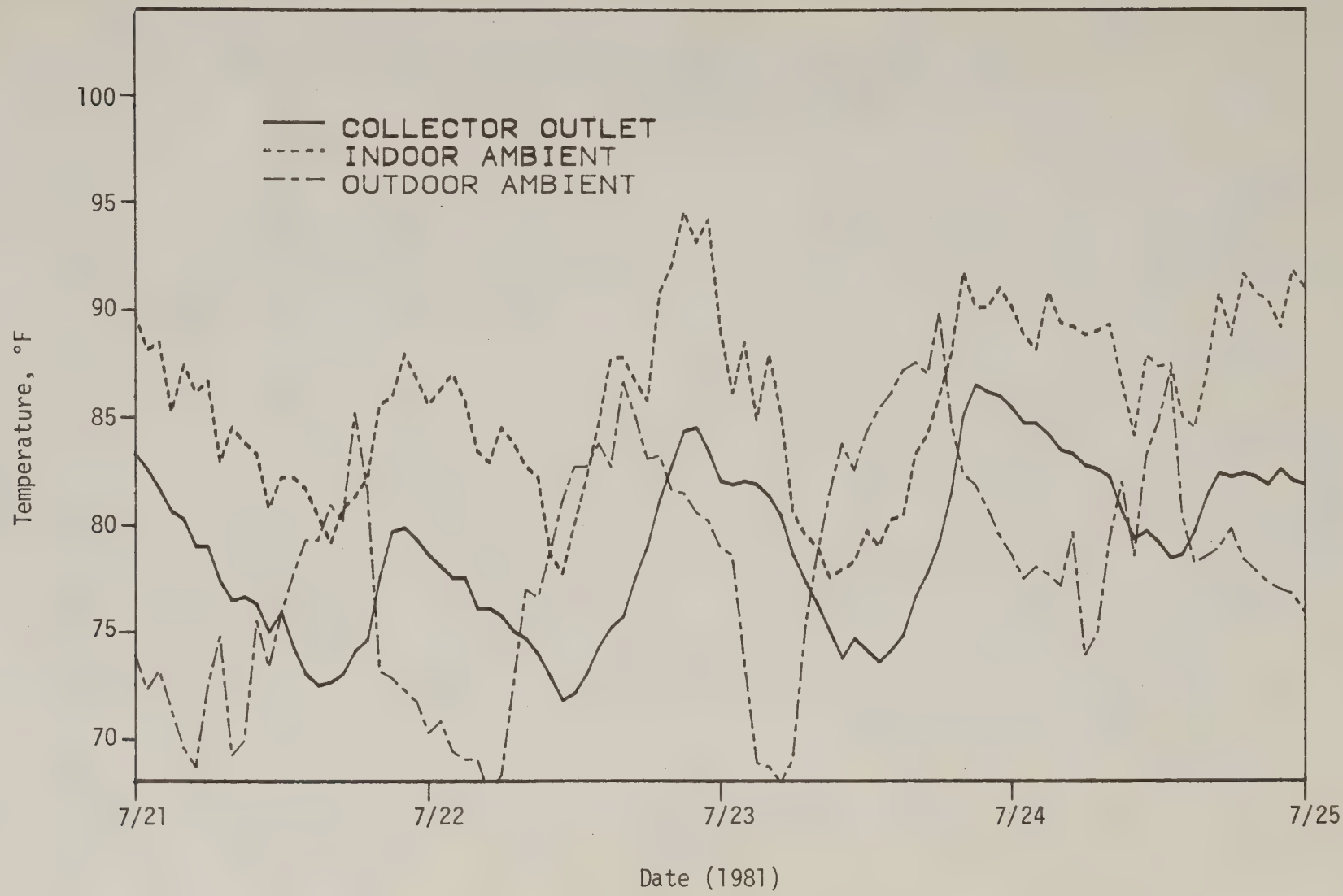


Figure 9. Farrowing room ventilation air cooling in the summer with the vertical solar wall (Buescher).

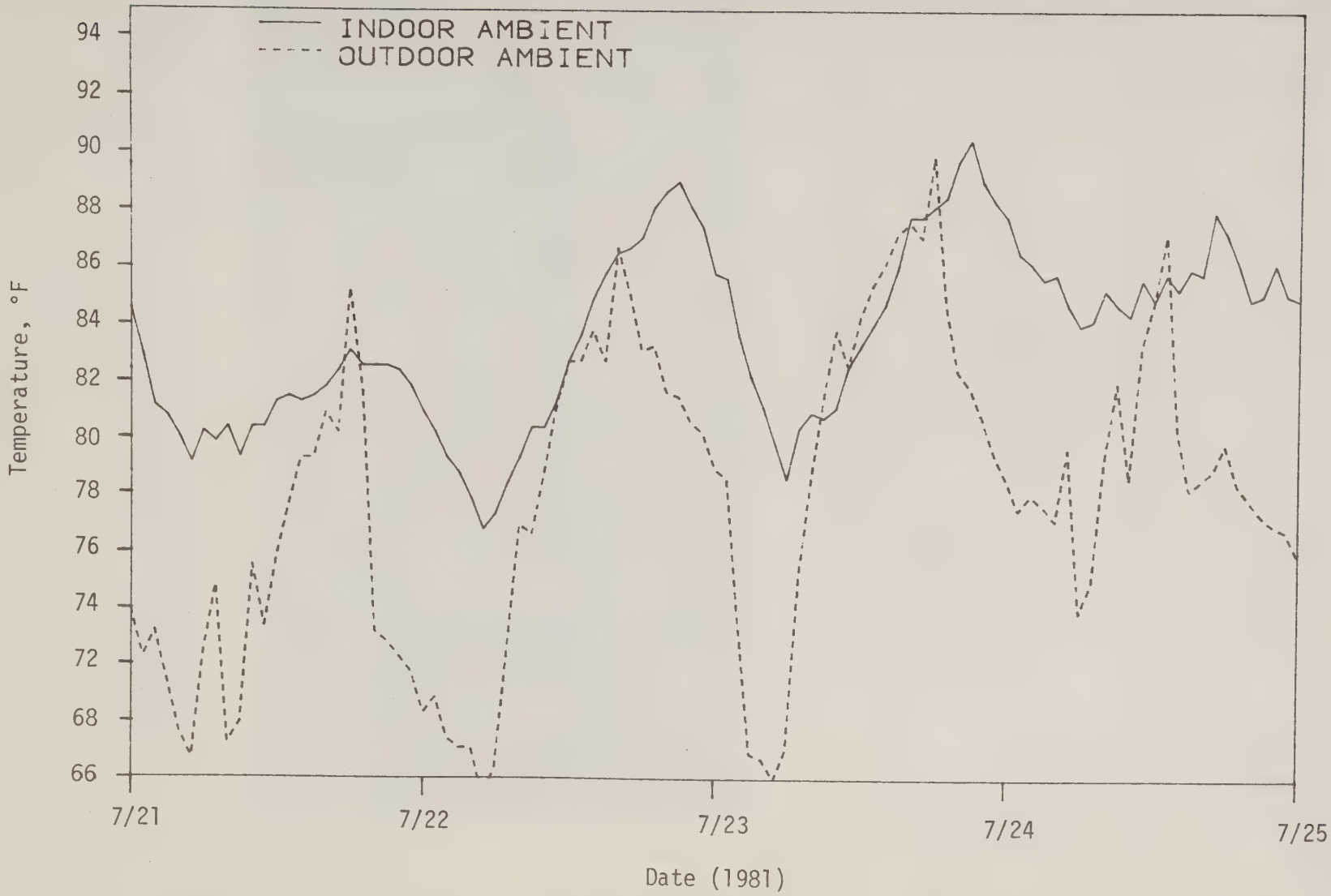


Figure 10. Outdoor air used to ventilate the nursery room during the summer (Buescher).

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SWINE FARROWING BUILDING WITH SLANT SOLAR WALL

Elwyn Fitzke
Glenvil, NE

Demonstration Project
Solar Heating of On-Farm Livestock Structures
Project NE-5



20-sow farrowing building with a slant wall for winter ventilation air preheating and summer water preheating.

UNIVERSITY OF NEBRASKA-LINCOLN, COOPERATING WITH THE COUNTIES AND THE U.S. DEPARTMENT OF AGRICULTURE

The University of Nebraska-Lincoln The University of Nebraska Medical Center The University of Nebraska at Omaha

SWINE FARROWING BUILDING WITH SLANT SOLAR WALL

Elwyn Fitzke
Glenvil, NE

THE FARM

Elwyn Fitzke and his father, Ward, own and operate the farm on which the demonstration facility is located. The farm (40°26'N, 98°10'W) is located in south central Nebraska's Clay County. The farming operation consists of raising corn and soybeans on 400 and 100 acres of irrigated land, respectively. Sorghum and soybeans are grown on 150 and 50 acres of dryland, respectively. The livestock operation includes a 50-cow herd cow-calf operation and a 60-sow farrow-to-finish operation producing between 900 and 1,000 market hogs per year.

The Fitzke's have cooperated with the University of Nebraska, the U.S. Department of Agriculture and the U.S. Department of Energy in designing and instrumenting this system. The Fitzke's constructed the solar heating system which was added on to the existing building. Information in this report includes a description of the farrowing house and the solar collector in both the ventilation air preheating and water heating modes. Guidelines on performance and operation of this system and suggested system modifications are also included.

GOALS

The design of the solar collector system was governed by the following objectives:

1) The solar collector system must be designed to allow the farmer or farm builder to construct the system with as much locally available material and equipment as is technologically and economically possible.

2) The system must be understandable and manageable by the farmer.

3) The system must be designed so the farmer can reasonably be expected to make any necessary repairs.

SYSTEM DESCRIPTION

A. The Farrowing Building

The 24 x 66 ft building contains a 24 x 60 ft farrowing room plus an office and sow wash in the east end of the building (See Figure 1). The building has a gable roof, is mechanically ventilated and utilizes in-floor water lines to provide a warm floor creep area for the young pigs. The farrowing room has two rows of 10 farrowing crates with the rear 30 in. of each crate over slats and an under-slat flushing gutter (See Figure 2). The ventilation system includes over-the-wall slot inlets with three exhaust fans located in a "bank" centered along the north wall of the building. Backup heat is provided by a propane-fired hot water heater which circulates warm water through the in-floor water lines when the building requires more heat than the solar collector can provide.

B. The Solar Collector System

The 450 ft^2 collector used on this building consists of concrete slats stacked in a triangular pile along the south wall of the building with a 60 degree sloped front absorber surface. The slat stack starts 6 in. away from the south building wall to provide a plenum for airflow (Figure 2). Horizontal gaps between each layer of slats in the stack are formed by using strips of flat metal bars to separate the slat layers. The thickness of the metal spacer bars is varied with the thinnest bars at the top and the thickest bars at the bottom of the collector. This feature of the design is to help maintain even airflow through the collector. The sloped south surface of the slats is painted flat black. Copper water lines are laid on top of the ledges formed by each layer of slats in the stack (See Figure 2). Two Filoplate® #556 glazing layers (outside layer corrugated, inner layer flat) cover the sloped slat stack and water lines.

There are several ventilation system operation modes on the collector which serve the needs of the building during different seasons. During the winter, ventilation air (1.5 cfm per ft^2 of collector) is preheated as it passes between the glazing layers, travels through the horizontal gaps between the slats into the plenum and then into the building through the over-the-wall slot inlet (See Figures 3 and 4). Backup heat is provided by the in-floor heat system.

In the spring and in the fall, warmer outside temperatures require higher ventilation airflow rates to remove heat from the building. Heated air is a detriment in this case so air is pulled through motorized shutters in the ends of the plenum allowing ventilation air to bypass the collector (See Figures 5 and 6). This air travels through the plenum behind the collector, through the over-the-wall slot inlet and into the building. This allows the collector to "stagnate" and store heat for use during cold nights (winter type operation).

For high airflow rate ventilation during the summer a baffle above the collector is opened to allow air to bypass the collector (over the

top) and go directly into the building. The over-the-wall slot inlets on the north side of the building are opened to provide enough inlet area for summertime ventilation (Figures 7 and 8).

The collector has no ventilation airflow through it during the summer, but is used to heat water for the in-floor heat system. Water is circulated through the collector water lines and is heated by the hot slats and air in the collector as well as by direct heat gain from solar radiation. This water is pumped to an insulated storage tank (See Figure 9). The in-floor heat system uses the heated water from the storage tank as heat is required. Plans are to use the solar water heating system only during the summer (water lines drained in the fall and refilled in the spring) and to use the collector only as a ventilation air preheater during the winter. When necessary, a fan in the end of the collector exhausts hot air from the collector to the outside to keep the collector from overheating.

COST

The collector system, including all the materials and labor, cost $9961.97 for 450 ft^2 of collector. This is $22.14 per ft^2 of collector area or $498.10 per sow. Note that this design includes a full 2 ft^3 of thermal storage mass per ft^2 of collector area and costs more than a vertical solar wall with 8 x 8 x 16 in. blocks having only 1.3 ft^3 of thermal storage mass per ft^2 of collector area. This cost includes all the extra equipment required to integrate the solar water heating system with the in-floor heating system. The water heating option represents $1943.69 or 19.5 percent of the solar collector system cost. The 20-sow farrowing building, without the solar collector system, cost $23,256, or $1163 per sow. The solar collector system added 42.8 percent to this cost.

PERFORMANCE

A. Thermal

The solar collector was installed to preheat winter ventilation air and to heat water for the in-floor heating system during the summer. The collector has been used to preheat winter ventilation air during two heating seasons.

The solar collector system added sufficient heat to the ventilation air to provide all of the 2.69 x 10^6 Btu of supplemental heat required during 19 days in November 1981. Indoor and outdoor temperatures during this time averaged 67 and 42°F, respectively. The range of outdoor temperatures was from 18 to 66°F. During a fourteen day period in late November and early December 1981, the collector provided 77 percent (2.76 x 10^6 Btu) of the 3.58 x 10^6 Btu required. For this time period indoor and outdoor ambient temperatures averaged 65 and 36°F, respectively, with a range of 22 to 58°F in outdoor ambient temperatures. A plot of the variations in the indoor, collector outlet and outdoor ambient temperatures during this time period are presented in Figure 10. The effect of stored

solar heat being released at night is evidenced by the continuation of a positive temperature difference between outdoor ambient and the ventilation air at the collector outlet.

Low hog prices and associated limits on cash flow, construction delays, and delays in obtaining some system components combined with functional problems to severely limit the use of the summertime solar water heating system. The result has been collection of insufficient useful data to permit a realistic evaluation of system performance. The cooperator has advised of his intentions to continue development, testing and operation of this component of the solar system despite termination of the overall project. To the extent possible, University of Nebraska Agricultural Engineers will participate in this continued effort.

B. Economic

With no data from the solar water heating operation of the collector, it is impossible to determine economic returns for this part of the system. The winter ventilation air preheating data are limited.

The normal winter heating season consists of 5973 heating degree days with a base temperature of 65°F. The indoor ambient air temperature of this building is normally kept at 72°F. With the exposure coefficient of 1053 Btu/hr·F° and an estimated heat production from the 20 sows and litters of 20,000 Btu/hr, the animals in the building can maintain a 72°F indoor ambient temperature if the outdoor ambient temperature is 53°F or above.

The normal winter heating season for this building consists of 3277 heating degree days with a base temperature of 53°F. With the given exposure coefficient and heating load, the annual heating requirement comes to 82.8×10^6 Btu. Assuming that the solar collector system provides 70 percent of this heat, normally provided by propane costing $0.56 per gal, the solar collector system should save 840 gal of propane or $471 annually. The $9917 collector system saving $471 annually has a simple payback period of 21.0 years. Additional savings from the summer water heating portion of the collector, as well as tax credits, interest, inflation and the time-value of money approach to determining the life cycle cost of the system would reduce this payback period.

C. Problems

The water heating part of the solar collector system was installed in accordance with initial design concepts but several problems kept it from operating long enough to allow collection of useful data. A discussion of these problems will hopefully prevent others from repeating these mistakes.

Zone control valves used to interconnect the solar heated water storage tank into the system that supplied hot water to the in-floor heat system failed to perform satisfactorily. An attempt was made to operate both valves off one thermostat to prevent conflicting valve settings.

However, the electrical circuit to initiate a change in valve position caused the valves to continually rotate. This situation developed due to slight differences in valve rotational speeds--and a resultant continuous electrical current through their controlling motors. The problem was solved by replacing the rotating zone control valves with solenoid valves.

A commercial water tank with sufficient capacity to store the required quantity of water was judged to be prohibitively expensive. This led to a decision by the cooperator to make his own tank out of 1/4 in. steel plate. The tank was constructed and installed. Pressurization of this tank, required for proper system operation, turned the tank from a rectangular box into a quasi-spherical shape. This was deemed unsafe and the system was shut down. Re-design of the solar water heating system resulted in this problem being circumvented. The revised system currently being installed allows operation of the storage tank as a nonpressurized container but requires two additional circulator pumps and associated controls.

COMMENTARY

A. Construction Suggestions

1) Glazing materials for the collector should be chosen to withstand ultraviolet light degradation and have good solar energy transmittance characteristics. The glazings must be able to withstand the impact of icicles and snow that drop off the roof during winter.

2) Be sure to seal the collector carefully except where airflow is desired. This will ensure proper airflow through the collector. Air leaks at the wrong places cause serious adverse effects on collector performance. It is much easier to seal joints during construction than to repair air leaks. Use only high quality, long lasting caulking materials. Clear silicone caulk is recommended.

3) All air inlets to the collector should be covered with 1/2 x 1/2 in. wire mesh screening to prevent birds from entering the solar system and the building.

4) Provide enough overhang so rain and snow do not blow into the collector inlet.

5) Install the collector on a one percent slope so the water lines lying on top of the slats will drain properly for winter collector operation.

6) Be sure to provide air bleed valves at the high point of all collector water lines to aid in collector drain-down for winter.

7) Be sure to use compatible materials in the storage tank for the water system, the in-floor heat system and the collector water line system. One example of non-compatible materials is an aluminum tank with copper water lines. This will result in corrosion problems in the water system.

8) Install all fans and shutters in a manner which allows access and/or removal for servicing and repair.

B. Suggested Modifications

1) The concrete slats are quite expensive and an alternative of using concrete blocks is considered possible. Having used concrete slats on hand would modify the economics.

2) For further information on the application of solar energy in your state contact your county Extension agent or Extension Agricultural Engineer at your Land-Grant University.

PROJECT MANAGEMENT

Work on this project was performed by the University of Nebraska Department of Agricultural Engineering. Individuals directly involved were Gerald R. Bodman, P.E., Extension Agricultural Engineer--Livestock Systems (Project Manager) and Michael F. Kocher, Extension Assistant (Project Coordinator). Inputs from the Departments of Agricultural Economics and Animal Science are acknowledged.

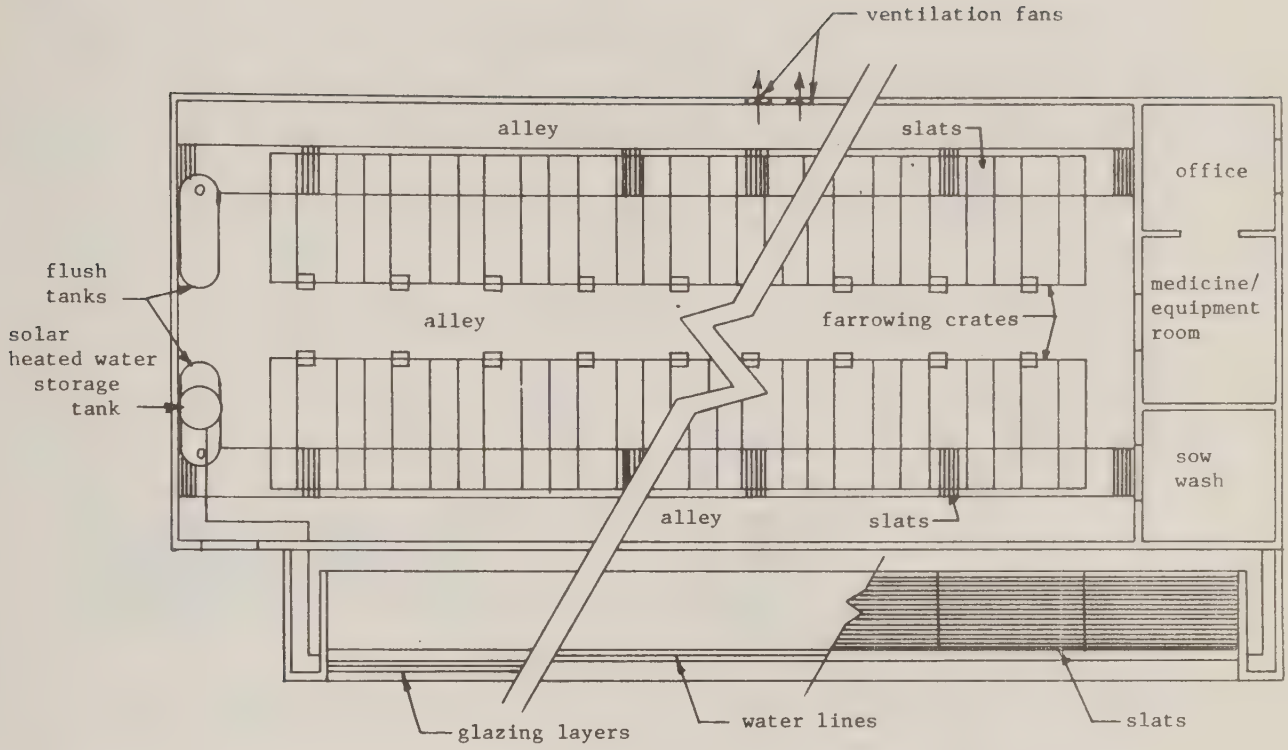


Figure 1. Floor plan for the 20-sow solarized farrowing unit. (Fitzke). Details omitted for clarity.

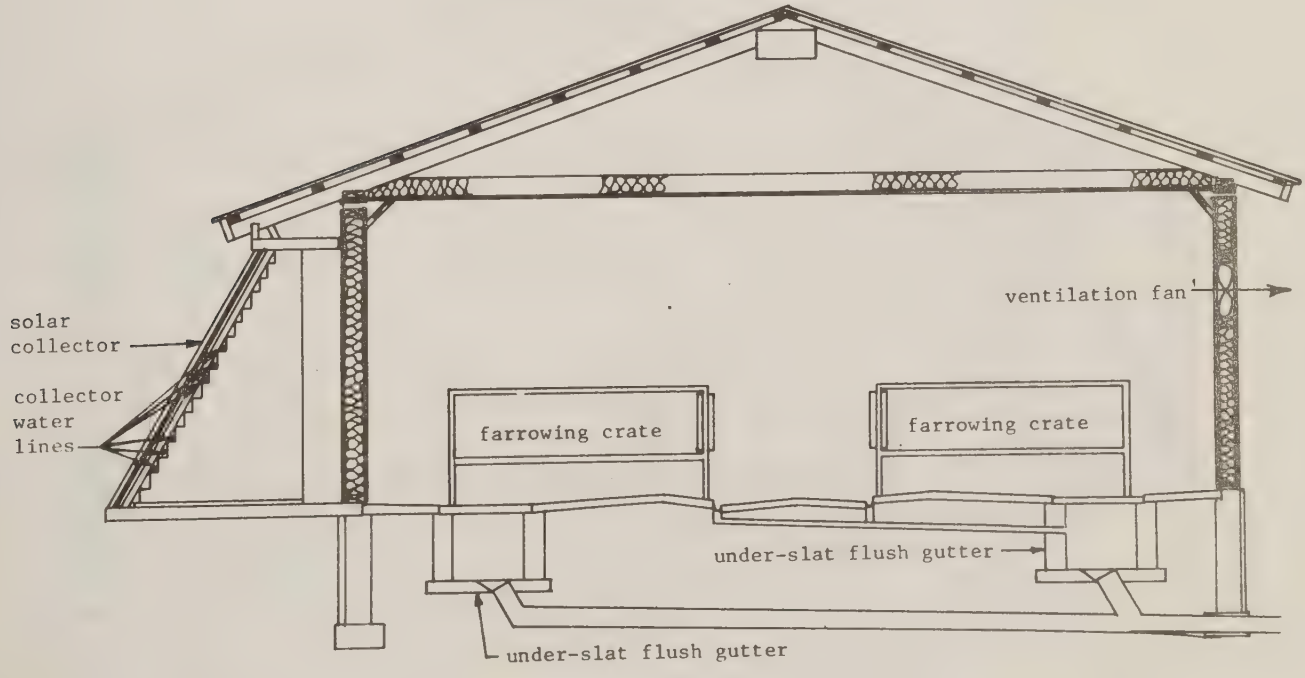


Figure 2. Partial building cross section (Fitzke). Details omitted for clarity.

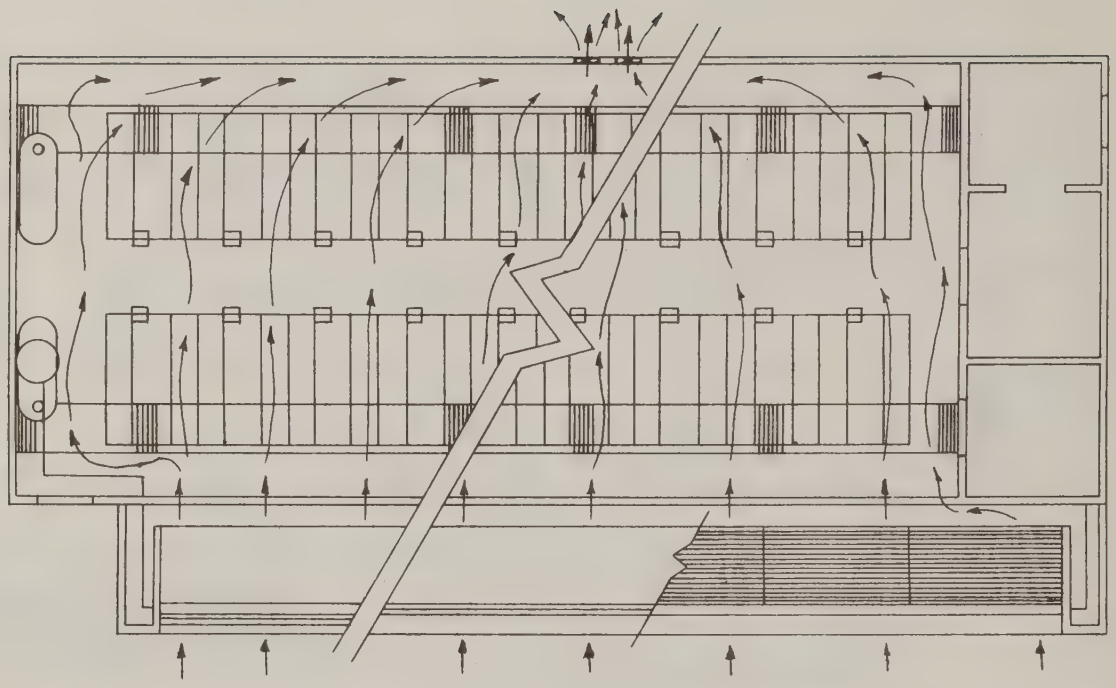


Figure 3. Floor plan schematic of winter ventilation airflow pattern (Fitzke). Details omitted for clarity.

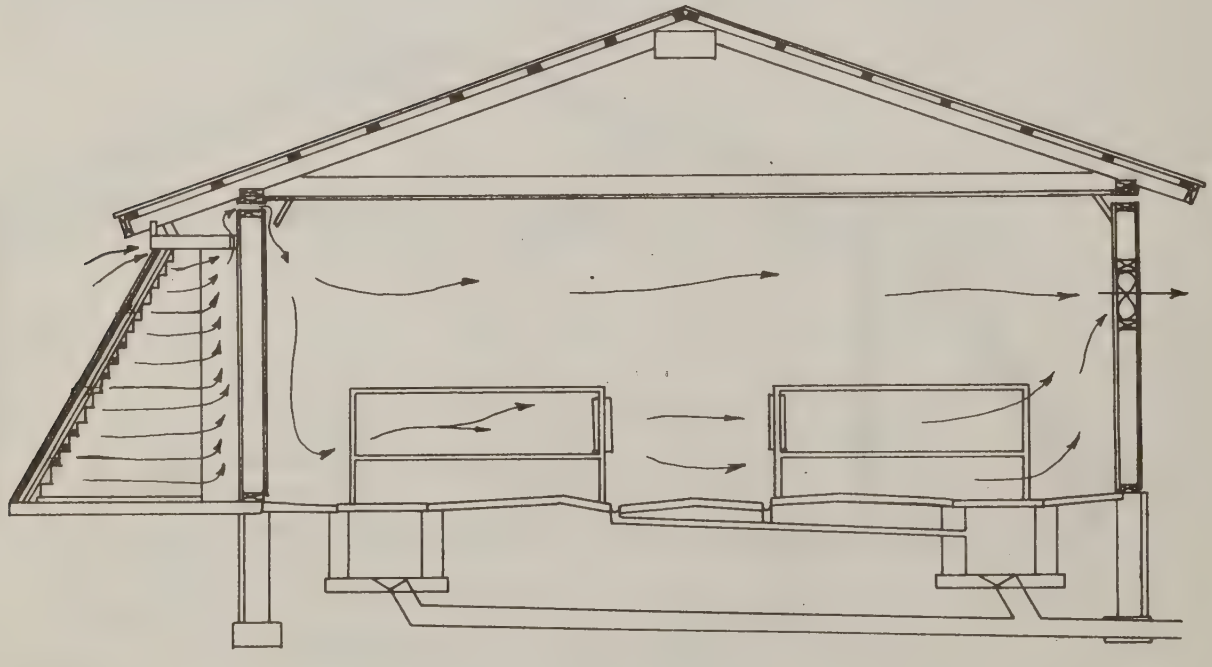


Figure 4. Cross section schematic of winter airflow pattern (Fitzke). Details omitted for clarity.

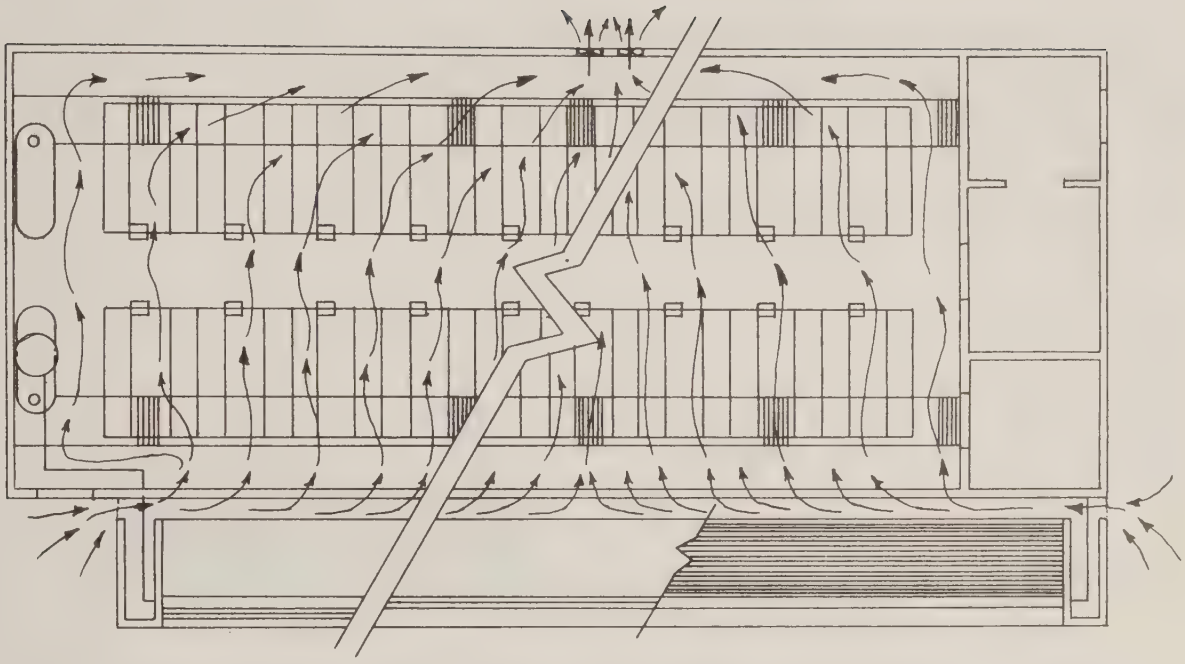


Figure 5. Floor plan schematic of spring/fall ventilation airflow pattern (Fitzke). Details omitted for clarity.

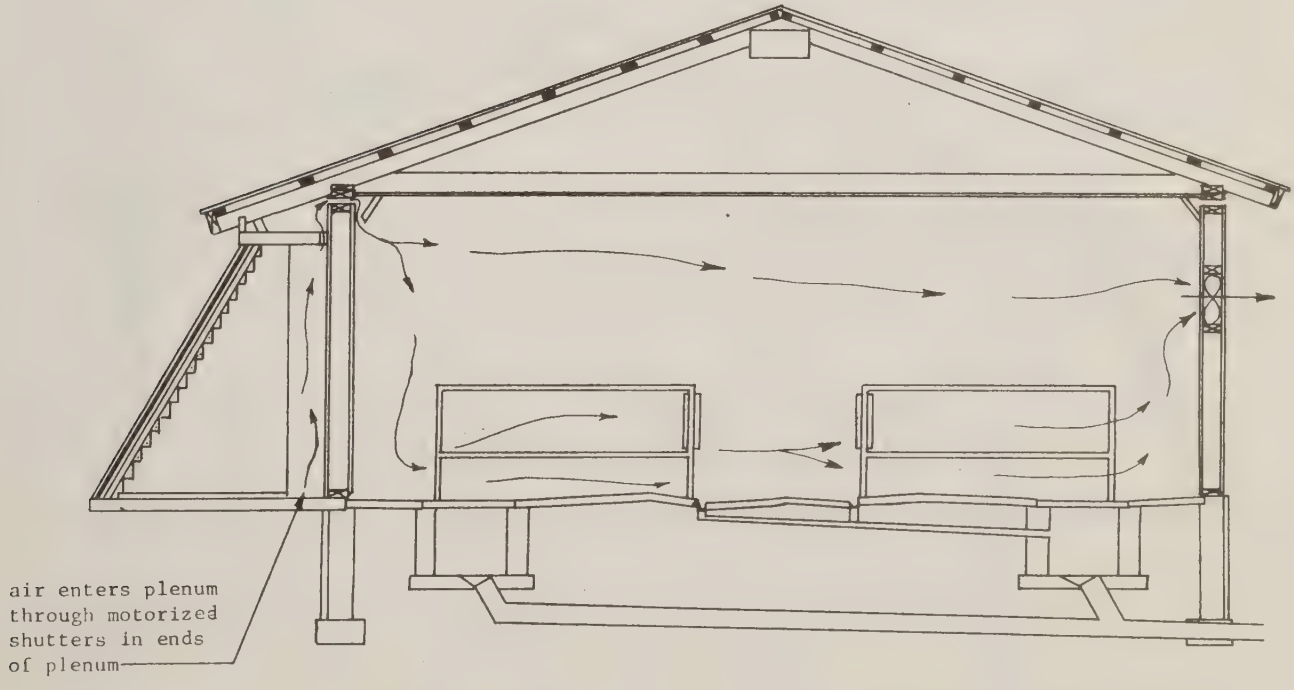


Figure 6. Cross section schematic of spring/fall ventilation airflow pattern (Fitzke). Details omitted for clarity.

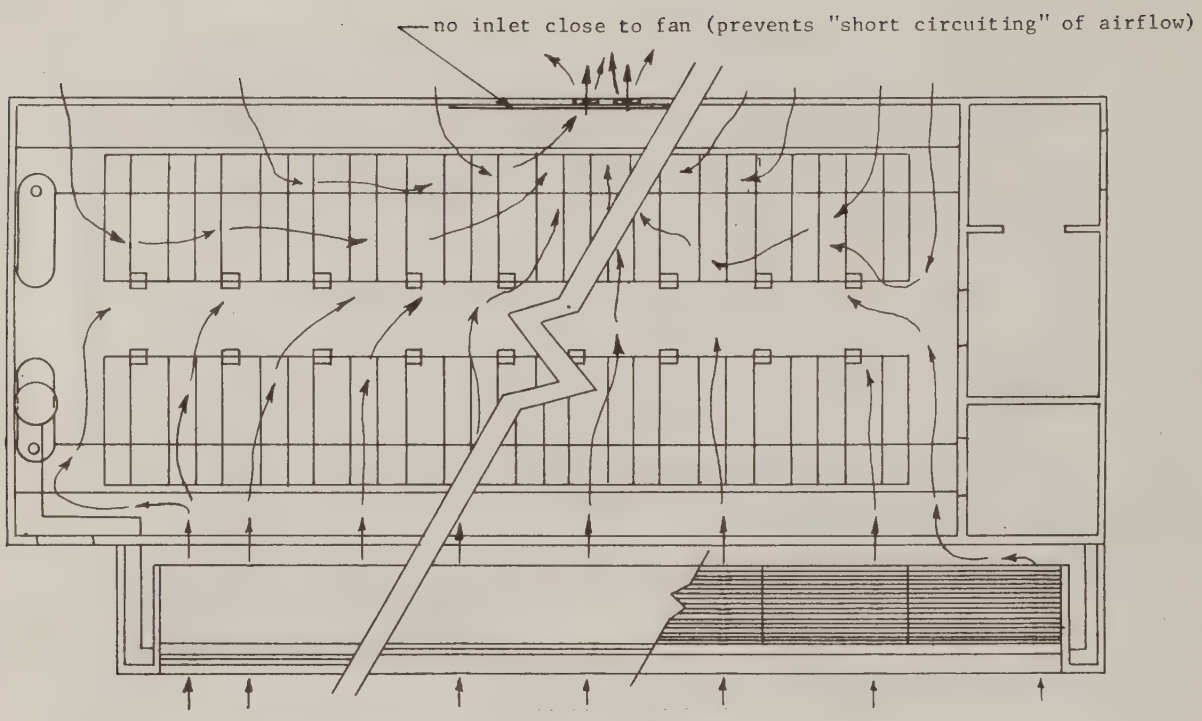


Figure 7. Floor plan schematic of summer ventilation airflow pattern (Fitzke). Details omitted for clarity.

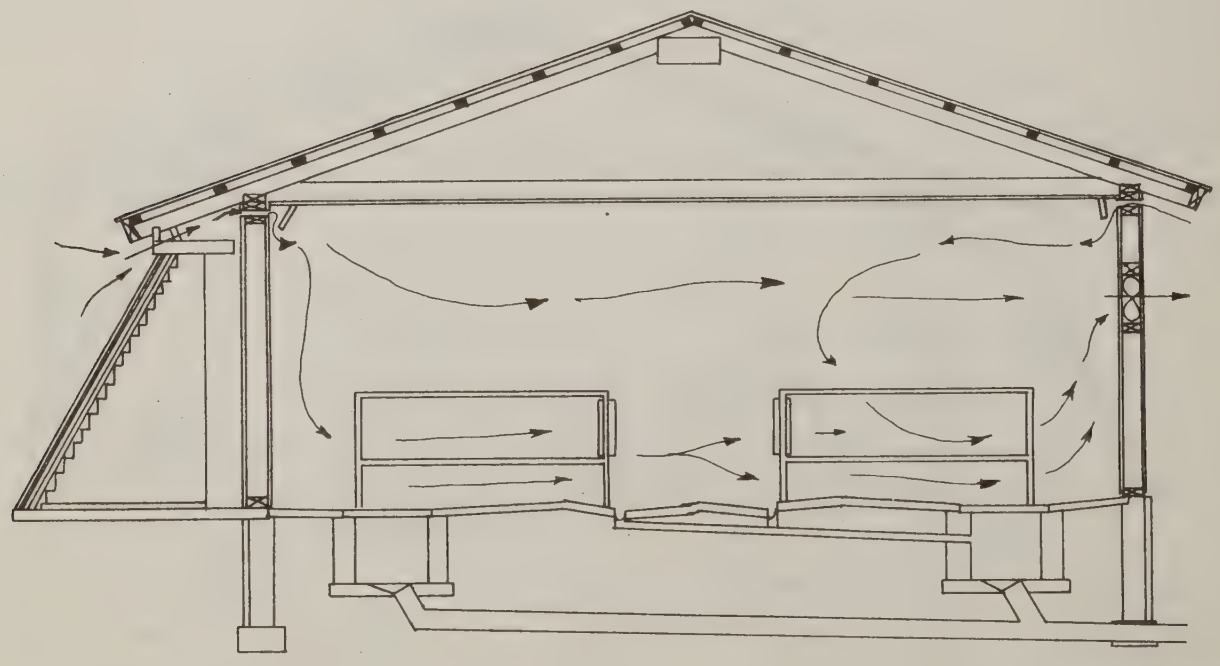


Figure 8. Cross section schematic of summer ventilation airflow pattern (Fitzke). Details omitted for clarity.

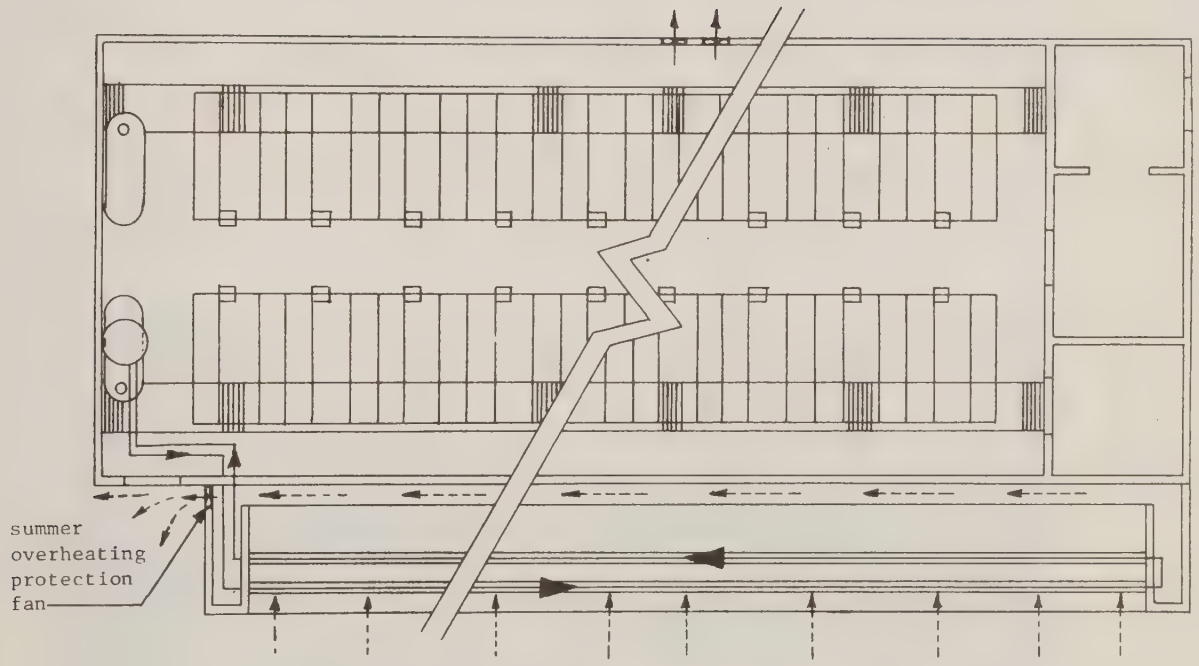


Figure 9. Floor plan schematic of summer water flow through the collector (Fitzke). Dotted arrows indicate airflow pattern on overheating protection. Details omitted for clarity.

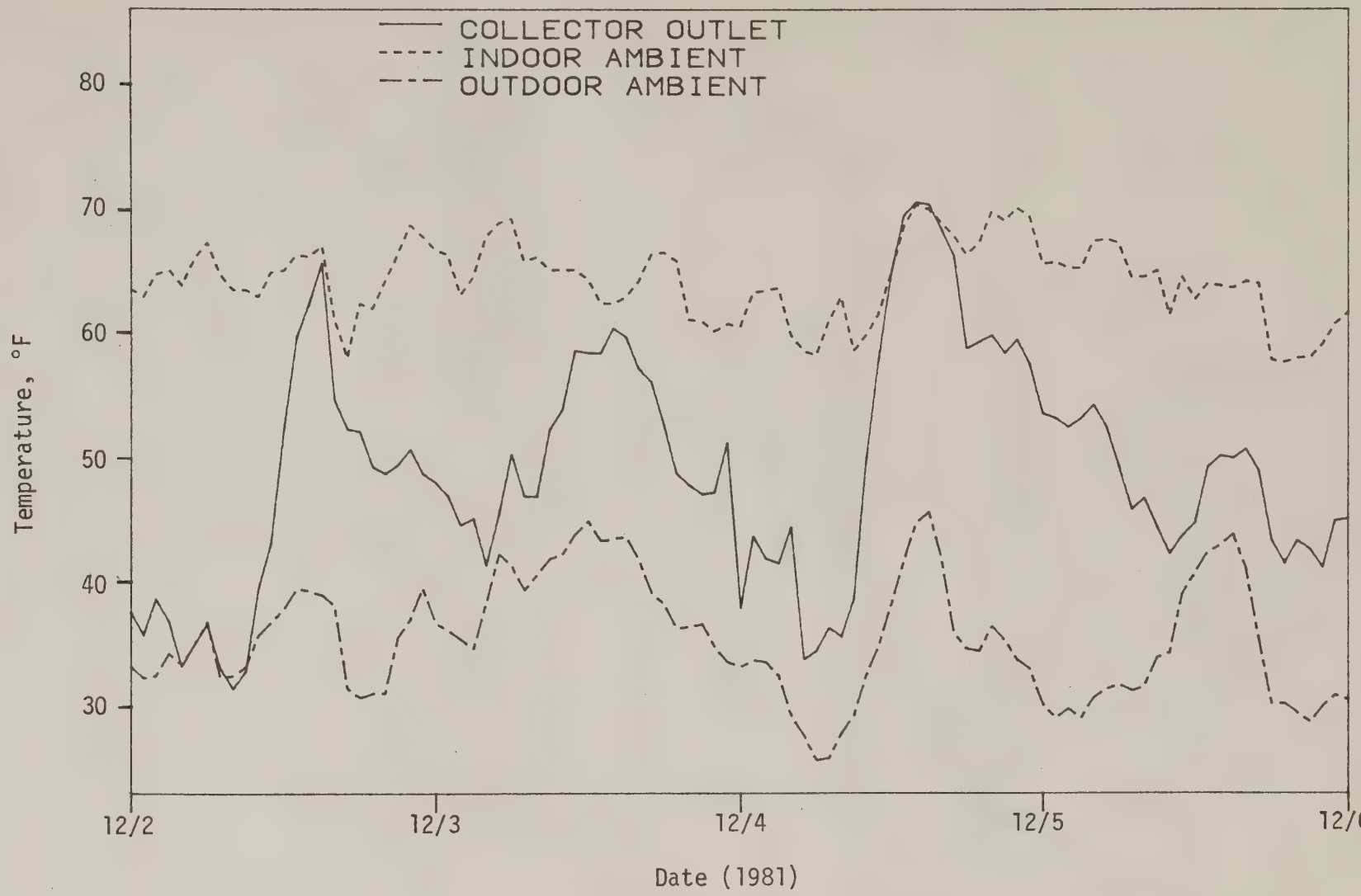


Figure 10. Farrowing house winter ventilation air preheating with the slant solar wall (Fitzke).

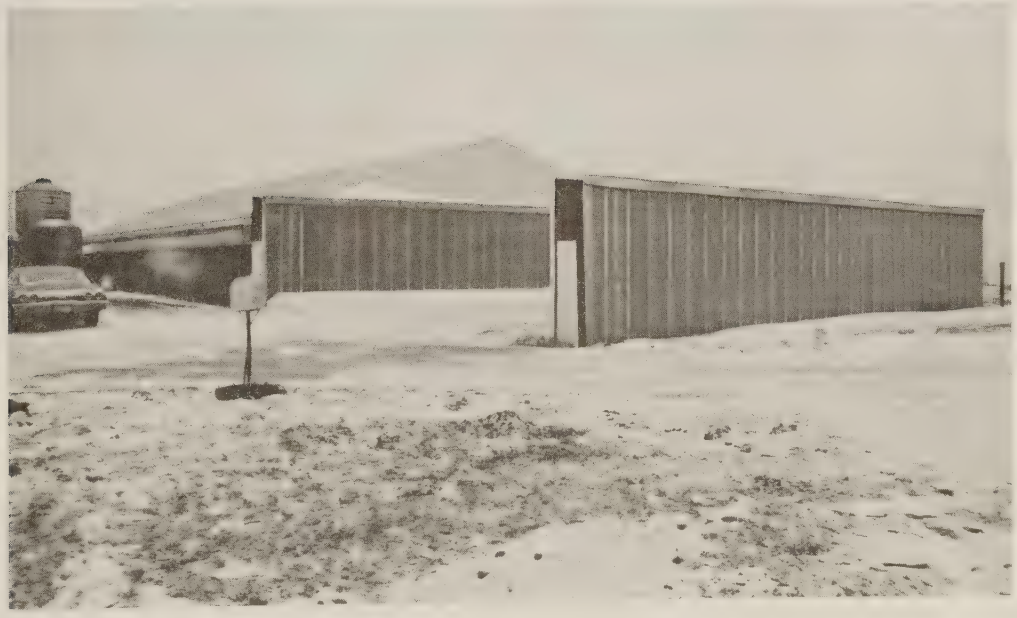
Cooperative Extension Service
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SWINE FARROWING COMPLEX WITH TWO VERTICAL SOLAR WALLS

Logan Valley Swine
Lyons, NE

Demonstration Project
Solar Heating of On-Farm Livestock Structures
Project NE-6



Vertical solar collectors (2) for preheating winter ventilation air for the 80-sow farrowing building (8-10 sow rooms).

UNIVERSITY OF NEBRASKA-LINCOLN, COOPERATING WITH THE COUNTIES AND THE U.S. DEPARTMENT OF AGRICULTURE

The University of Nebraska-Lincoln The University of Nebraska Medical Center The University of Nebraska at Omaha

SWINE FARROWING COMPLEX WITH TWO VERTICAL SOLAR WALLS

Logan Valley Swine
Lyons, NE

THE FARM

Logan Valley Swine Breeders, Inc. is a pig coop which is located in northeastern Nebraska's Burt County. The solar site is located at 42°2'N, 96°29'W. The operation consists of a 500-sow farrow-to-finish operation marketing 8500 hogs per year. Jim Blasey is the manager of the facilities to which the solar system was added.

Logan Valley Swine, Inc. has cooperated with the University of Nebraska, the U.S. Department of Agriculture, and the U.S. Department of Energy in designing, constructing, instrumenting and monitoring this system. Information in this report includes a description of the farrowing facility, a description of the solar system and the cost of the system. Some system performance results and suggestions for the operation and modification of this system are also included.

GOALS

The design of the solar collector system was governed by the following objectives:

1) The solar collector system must be designed to allow the farmer or farm builder to construct the system with as much locally available material and equipment as is technologically and economically possible.

2) The system must be understandable and manageable by the farmer.

3) The system must be designed so the farmer can reasonably be expected to make any necessary repairs.

SYSTEM DESCRIPTION

A. The Solar Farrowing Building

The farrowing building contains 8 rooms with 10 farrowing crates per room (See Figure 1). The farrowing crates have full wire mesh floors above deep pits (See Figure 2). Ventilation is accomplished by bringing fresh air into a connecting hallway across the west end of the farrowing rooms. The air then moves through inlets over the west wall of each room and is exhausted from above the manure in the pit by a fan at the east end of each room. Heat lamps are used as necessary for the newborn pigs. A vented radiant heater provides heat to the farrowing rooms when the solar collector cannot meet the farrowing building demand for heat.

B. The Solar Collectors

Two solar collectors are used to preheat winter ventilation air and cool summer ventilation air for the farrowing building. The 55 x 10 ft northernmost collector is attached to the south wall of the farrowing building and uses concrete slats (2.0 ft^3 of thermal storage mass per ft^2 of collector) stacked with thin metal spacer bars between the slat layers to provide horizontal gaps for airflow through the slats (See Figure 3). The metal spacer thicknesses were varied, with the thickest spacer bars in the east third of the collector, the medium thickness in the middle third, and the thinnest spacer bars in the west third of the collector. This was done to help maintain even airflow through the collector. The south face of the slats is painted black and covered with two layers of Filoplate® #556 glazing (inner layer flat, outer layer corrugated) to form the collector. A 3 in. space between the back of the collector and the south building wall serves as an air plenum and duct for the system.

The south collector, also 55 x 10 ft, uses 6 x 8 x 21 in. (nominal) solid concrete blocks for the heat storage (approximately 1.4 ft^3 of thermal storage mass per ft^2 of collector) and absorber (See Figure 3). The spacing between the blocks is varied in the same manner as in the north collector to help maintain even airflow through the collector. The south side of the blocks is painted black and covered with the double glazing layers to form the collector. The southern collector is free-standing and is located approximately 35 ft south of the north collector. A 24 in. diameter insulated underground culvert serves as a connecting air duct between the south collector and the farrowing building (See Figure 4).

Air enters the collectors at the slot inlets near the eave overhang and travels between the glazings to the bottom of the collectors. A slot at the bottom of the inner glazing allows the air to travel between the inner glazing and the black surface of the blocks or slats, gradually filtering through the vertical gaps between blocks or horizontal spaces between slats. Once the air reaches the plenums behind the slats or blocks, it travels westward to the ends of the collectors. Air from the south collector then goes down into the underground culvert and travels through the culvert to the west end of the north collector. At this point, air from the two collectors mixes and enters the farrowing building hallway to provide preheated (or cooled, during the summer) ventilation air to the

farrowing rooms (See Figure 5). A collector flowrate of 2.5 cfm per ft^2 of collector area occurs during a normal winter ventilation airflow of 35 cfm per sow.

COST

The total cost for the materials and labor to install both collectors was $16,704.63 for 1100 ft^2 of collector area or $15.19 per ft^2. Calculating this on a per sow basis translates to $208.81 per sow. No farrowing building construction cost data were obtainable.

PERFORMANCE

A. Thermal

Several problems prevented gathering sufficient data for analysis of the thermal and economic performance of this solar collector system. Despite this shortfall, several comments about the collector system can be made from the data available.

The structural support system for the free-standing collector has not shown any signs of failure, despite several occasions of wind speeds in excess of 60 mph. Thermal performance of this collector indicates insulation levels in the collector are adequate.

The temperature of air leaving the north collector normally varies from the temperature of the air leaving the south collector by only 3F° indicating airflow through the two collectors is nearly the same. The temperature drop of the air that passed through the underground air duct between the south collector and the north collector was normally 2F° showing that insulation of this duct was adequate. The temperature rise from the collectors in August and September of 1981 averaged 16F°.

Although this particular system does not have data for analysis, it is based on sound engineering principles. Extrapolation of performance data based on the minimal amount of information available and the performance of similar but smaller collector designs indicates the design concepts incorporated were valid and offer an alternative for retrofitting large existing installations.

B. Problems

A problem with the data logger prevented gathering much data during the first winter. Some malfunction of equipment kept the data cassette tape operating when it should have been off. Thus, one side of a data cassette tape filled up in less than two days rather than the normal time of 3 weeks.

A change in management, and management philosophy regarding the use of solar energy, kept the solar collector from being used during the second winter. No data could be collected under these circumstances.

The hallway serves as the duct from the solar collector to the farrowing rooms during the winter. In the summer, it serves as the duct from the evaporative coolers to the farrowing room. This may be a problem in that it is difficult to seal the alternate openings, preventing air leakage at low static pressure differences and airflow rates.

COMMENTARY

A. Construction Suggestions

1) Select only glazing materials which are resistant to ultraviolet light degradation and have good solar energy transmittance characteristics.

2) Be sure to seal the collector carefully except where airflow is desired. This will ensure proper airflow through the collector. Air leaks at the wrong places can greatly affect collector performance. It is much easier to seal joints during construction than to repair air leaks. Use only high quality, long-life caulking. Clear silicone caulk is recommended.

3) All air inlets to the collector should be covered with 1/2 x 1/2 in. wire mesh screening to prevent birds from entering the solar system and the building.

4) Provide enough overhang so rain and snow do not blow into the collector inlets. Do not use excessive overhang as this results in shading the collector.

5) Any collectors not attached to a building (free-standing) must be designed and built to withstand normal building loads including wind and snow loads.

B. Operation Suggestion

Some cooling of summer ventilation air can be accomplished without covering the collectors. However, it is recommended that the collectors be covered during the summer for increased cooling capacity. Do not cover the air inlets to the collectors!

C. Suggested Modifications

1) The use of the free-standing south collector greatly increased the cost per ft^2 of collector area for the total system. The free-standing collector was used in this instance only because calculations showed that more collector area was required than could be obtained with a collector attached to the building (on-site space limitations). It is recommended that collectors be attached to the south side of the building wherever possible and free-standing collectors be added only when extra collector area is required. This procedure reduces construction costs as well as exposed surfaces through which heat loss can occur.

2) Different footings were used underneath the north and south collectors due to the different storage materials. The 10 ft long slats were supported at the ends only and required footings 10 ft on-center perpendicular to the building. The solid blocks were supported on rigid insulation which covered the floor of the south collector and required a trenched footing underneath the full length of the south collector. Be sure to use a footing design compatible with the storage material.

3) For further information on the application of solar energy in your state contact your county Extension agent or Extension Agricultural Engineer at your Land-Grant University.

PROJECT MANAGEMENT

Work on this project was performed by the University of Nebraska Department of Agricultural Engineering. Individuals directly involved with the project were Gerald R. Bodman, P.E., Extension Agricultural Engineer--Livestock Systems (Project Manager) and Michael F. Kocher, Extension Assistant (Project Coordinator). Inputs from the Departments of Agricultural Economics and Animal Science are acknowledged.

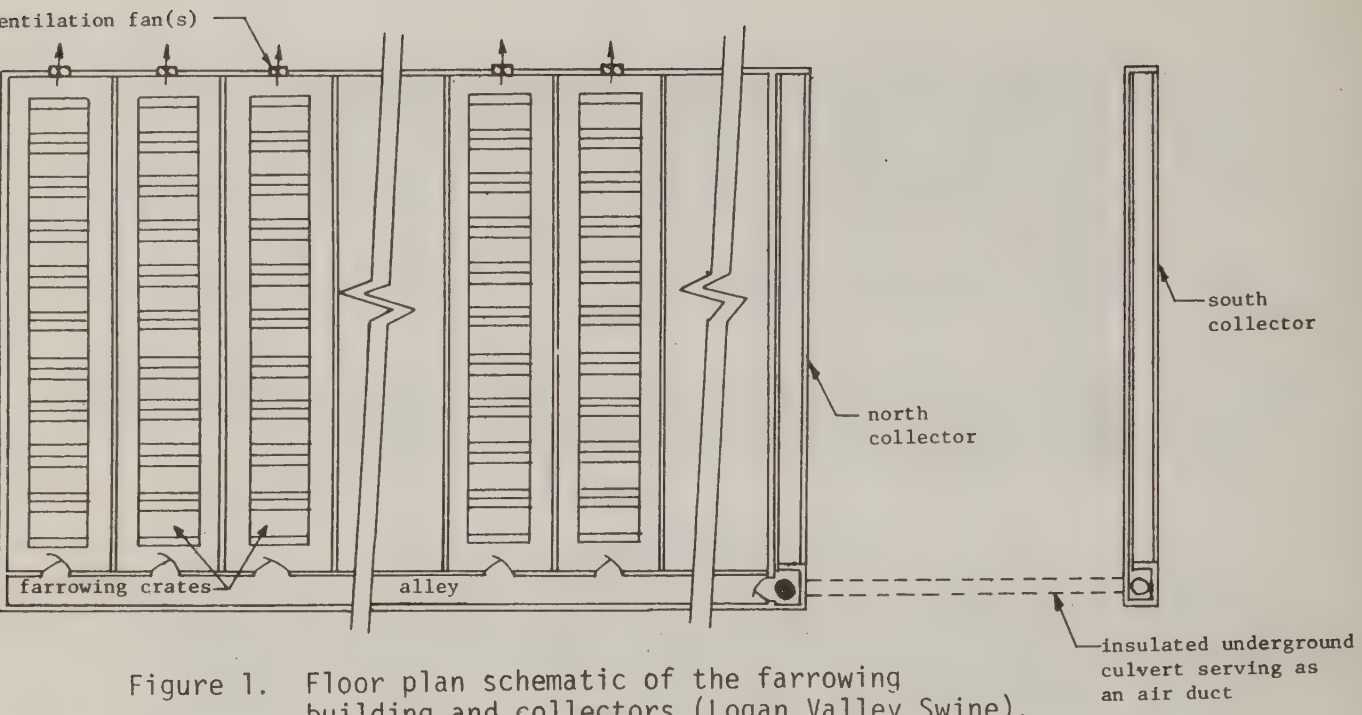


Figure 1. Floor plan schematic of the farrowing building and collectors (Logan Valley Swine). Details omitted for clarity.

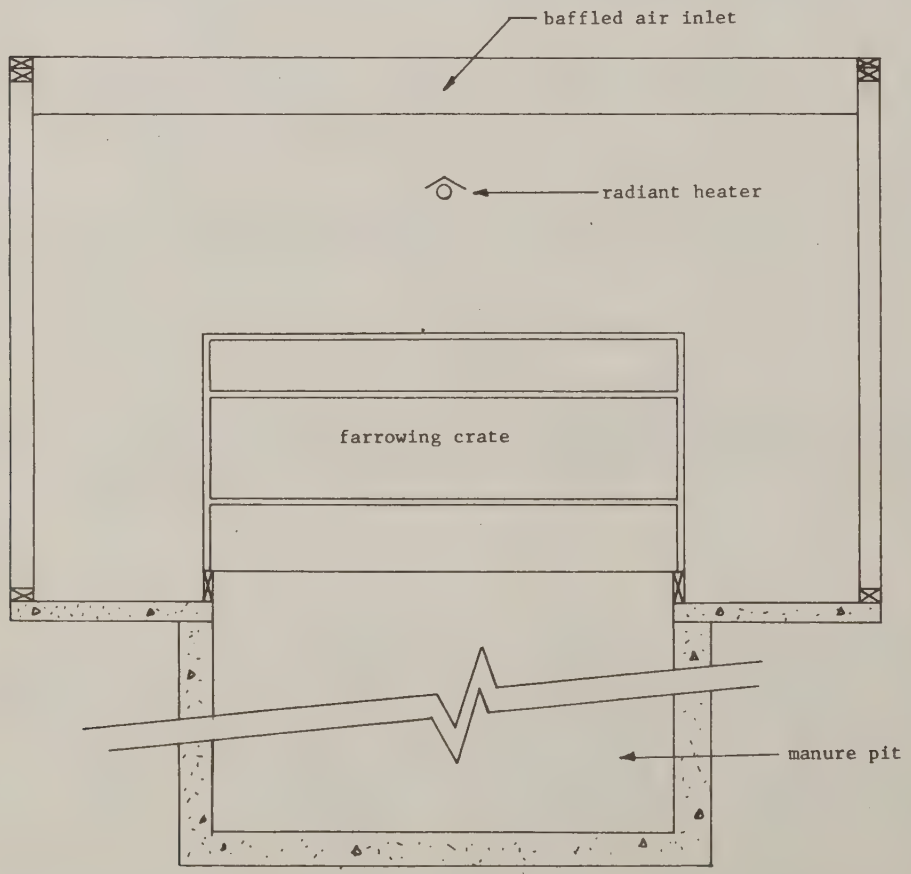


Figure 2. Cross section schematic of a farrowing room. (Logan Valley Swine). Details omitted for clarity.

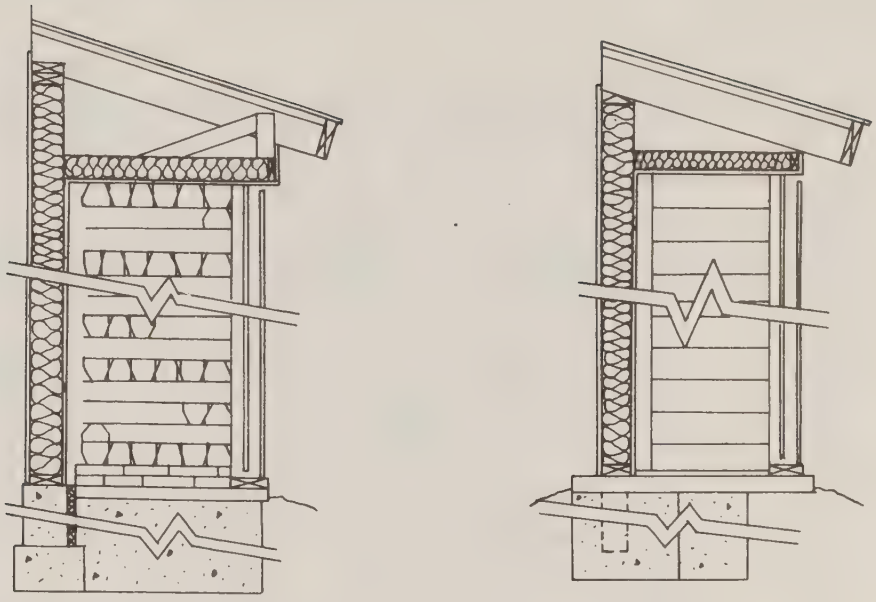


Figure 3. Partial cross sections of the north (left) and south (right) collectors (Logan Valley Swine). Details omitted for clarity.

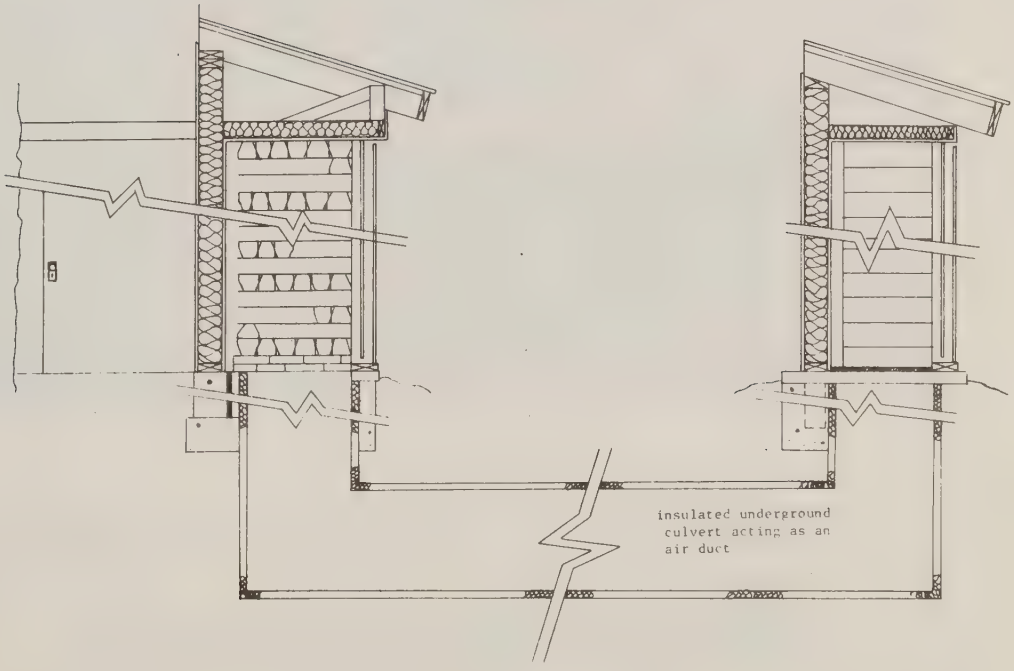


Figure 4. Partial cross section of the collectors and the connecting underground duct (Logan Valley Swine). Details omitted for clarity.

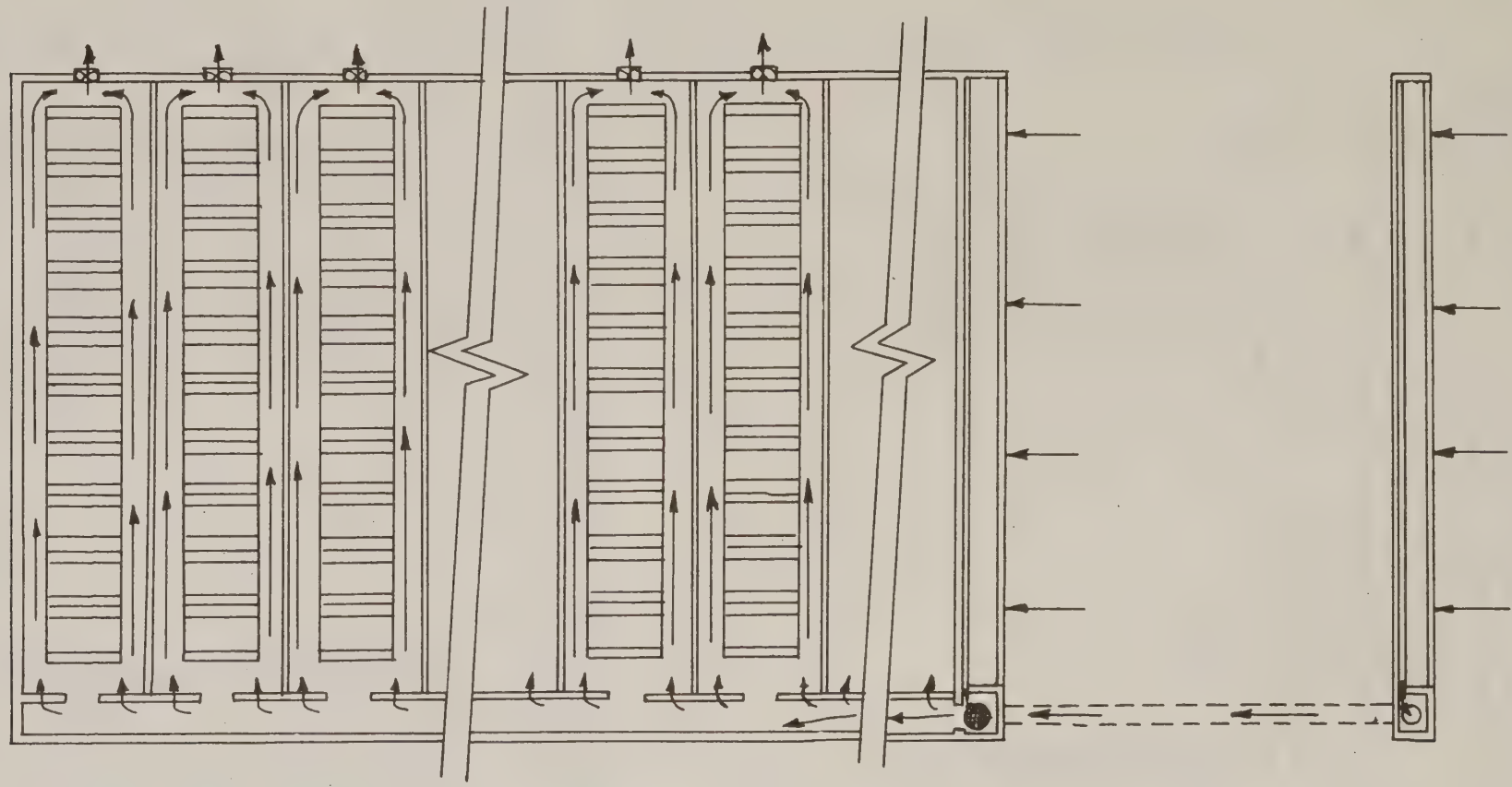


Figure 5. Floor plan schematic showing winter ventilation air movement (Logan Valley Swine). Details omitted for clarity.

Cooperative Extension Service
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COMBINATION SWINE FARROWING-NURSERY WITH VERTICAL SOLAR WALL

Phil Menke
Cozad, NE

Demonstration Project
Solar Heating of On-Farm Livestock Structures
Project NE-7



16-sow farrowing-240 pig nursery building with solar collector for preheating or cooling ventilation air.

UNIVERSITY OF NEBRASKA-LINCOLN, COOPERATING WITH THE COUNTIES AND THE U.S. DEPARTMENT OF AGRICULTURE

The University of Nebraska-Lincoln The University of Nebraska Medical Center The University of Nebraska at Omaha

COMBINATION SWINE FARROWING-NURSERY WITH VERTICAL SOLAR WALL

Phil Menke
Cozad, NE

THE FARM

Phil Menke owns and operates the farm on which this demonstration facility is located. The farm (40°53'N, 99°53'W) is located in central Nebraska's Dawson County. Dryland farming operations include approximately 30 acres of soybeans, 15 to 30 acres of wheat and 80 acres of alfalfa. Irrigated farming operations consist of raising corn on 130 acres. The livestock portion of the farming operation consists of a 60-sow farrow-to-finish operation with annual production of approximately 900 market-weight hogs.

The Menkes have cooperated with the University of Nebraska, the U.S. Department of Agriculture, and the U.S. Department of Energy in designing, constructing, instrumenting and monitoring this system. This report includes descriptions of the farrowing-nursery building and the solar collector system as well as the cost of the system. Guidelines on constructing this system and suggested system modifications are also included.

GOALS

The design of the solar collector system was governed by the following objectives:

1) The solar collector system must be designed to allow the farmer or farm builder to construct the system with as much locally available material and equipment as technologically and economically possible.

2) The system must be understandable and manageable by the farmer.

3) The system must be designed so the farmer can reasonably be expected to make any necessary repairs.

SYSTEM DESCRIPTION

A. The Farrowing-Nursery Building

Two 22 x 46 ft rooms are connected side-by-side to make up the 44 x 46 ft farrowing-nursery building. The facility is a gable roof, mechanically ventilated building utilizing in-floor warm water lines to provide a warm floor creep area for the young pigs. The farrowing room contains two rows of 8 farrowing crates with the front of the crates facing the walls. An 8 ft wide slatted area with an under-slat flush gutter runs down the center of the farrowing room. The nursery side of the building has the same configuration except that pens are utilized instead of farrowing crates and the alleys at the sidewalls do not exist in the nursery room (See Figure 1). The nursery room is smaller than the farrowing room because an office and a sow wash occupy the east 10 ft of the nursery side of the building.

A ventilation duct runs the length of the building above the divider wall between the two rooms. This ventilation duct is not divided but has continuous slot inlets the full length of the duct opening into each room. The nursery room is on the south side of the building and ventilation fans for this room are centered in a bank along the south wall and vented through the collector to the outside. The farrowing room is on the north side of the building and has ventilation fans in a bank centered along the north wall exhausting ventilation air directly to the outside (See Figure 2).

B. The Solar System

The 300 ft^2 vertical solar wall uses concrete slats (approximately 2.0 ft^3 of thermal storage mass per ft^2 of collector) stacked vertically with thin metal spacer bars between the slat layers to provide horizontal gaps for airflow through the slats (See Figure 3). The metal spacer thicknesses were varied, with the thinner spacer bars at the top and thicker spacer bars at the bottom of the collector. This was done to help ensure even airflow through the collector. The south face of the slats is painted black and covered with two layers of Filoplate® #556 glazing (inner layer flat, outer layer corrugated) with slots for ventilation air inlets. A 3 in. space between the back of the collector and the south building wall serves as an air plenum and duct for the system.

During the winter, ventilation air (5.7 cfm per ft^2 of collector) is pulled through the slots in the glazings and is warmed by traveling through the gaps in the collector slats on its way into the plenum chamber behind the slats. From there the air can travel directly into the farrowing room through two ducts, one each at the east and west ends of the building that supply air to the central ventilation duct, and into the nursery room. The central ventilation duct supplies air to the north side of the farrowing room and the south side of the nursery. During the winter the north wall slot ventilation inlets to the nursery room are completely closed to prevent cold outside air from entering the nursery room. Small openings may be required in the north wall slot ventilation inlets to prevent "dead air" spots in the nursery room. Continuous operation ventilation fans

in both the farrowing and nursery rooms cause a continuous airflow through the collector and through the ventilation ducts into the animal spaces from which the air is discharged to the outside. Air moving through the animal spaces picks up odors, gases and moisture for subsequent discharge from the building (See Figures 3 and 4). The in-floor heat water lines provide the back-up heat for the building when the solar collector cannot meet the building heating demands. Water for this system is heated by a conventional water heater.

Motorized shutters in the ends of the central ventilation duct are wired in parallel with the spring/fall fans. When the thermostats sense higher temperatures and a need for additional ventilation (i.e., warm spring/fall days) the motorized shutters open, allowing outdoor air to be pulled through the central ventilation duct (See Figures 5 and 6). This allows the collector to "stagnate", conserving the stored solar heat for use during cool evening or nighttime hours.

During the summer the collector is covered to provide cooling for the ventilation air. Cool night air is passed through the collector to cool the slats. During the day, the warm ventilation air is cooled as it passes through the collector before entering the building. Covers on the ends of the central ventilation duct can be removed for increased ventilation airflow during the hottest part of the summer, when the collector cannot adequately cool the ventilation air for the building (See Figures 7 and 8). Under this operational mode, sow cooling is accomplished through a combination of "wind chill" and evaporative cooling associated with evaporation of moisture from floor surfaces.

COST

The cost for the materials and labor for the solar collector system was $5446.16 for 308 ft^2 of collector or $17.68 per ft^2. These cost data do not include costs for interest or tax returns, and are only first cost data. No total installation cost data were obtainable from the cooperator.

PERFORMANCE

A. Thermal and Economic

No data that would allow any thermal or economic analyses of the solar collector system performance were gathered. Problems relating to this lack of data are related in part B of this section.

The efficiency of this collector should be slightly higher than efficiencies of other vertical solar wall collectors because the airflow through the collector is higher than in most vertical solar walls. This higher airflow is because of the side-by-side farrowing and nursery rooms, rather than an end-to-end construction with a vertical solar wall along the south side of each room. The increase in efficiency because of the increased airflow may be offset by the increased static pressure and

temperature loss of the solar heated air as it passes through the ducts in the attic that allow the solar heated air to enter the north room of the building (farrowing room). Whether the efficiency of the collector experiences a net increase or decrease, the temperature rise of air passing through the collector will not be as great with this increased airflow.

B. Problems

After completion of the solar collector system, a decision by the cooperator to change the ventilation system resulted in non-operation of the system until the middle of the '81-'82 winter. A nearly concurrent disease outbreak at this time forced the cooperator to immediately depopulate the building for six months in order to break the disease cycle. This prevented data gathering during the '81-'82 winter. An early termination date for the project prevented gathering data during the '82-'83 winter.

COMMENTARY

A. Construction Suggestions

1) Use glazings that are resistant to ultraviolet light degradation and have good solar energy transmittance characteristics.

2) Be sure to seal the collector carefully except where airflow is desired. This will ensure proper airflow through the collector. Air leaks at the wrong places can greatly affect collector performance. All air duct joints must also be well sealed. It is much easier to seal joints during construction than to repair air leaks. Use only high quality, long-life caulking. Use of clear silicone caulk is recommended.

3) All air inlets to the collector and air ducts should be covered with 1/2 x 1/2 in. wire mesh screening to prevent birds from entering the solar system and the building.

4) Provide enough overhang so rain and snow do not blow into the collector inlet.

5) Provide hoods over the motorized shutters and inlets to the ventilation ducts to prevent rain from entering the ducts.

B. Suggested Modifications

1) Side-by-side room construction in this building complicated the ventilation system construction and operation by requiring the central ventilation duct and the two cross ducts. End-to-end room construction is recommended in that virtually all duct work is eliminated and proper ventilation can easily be accomplished with over-the-wall slot inlets.

2) The slats used in this collector are becoming more and more expensive. It is possible to use solid concrete blocks in these collectors, however the footing for the collector must be modified to accommodate the use of blocks rather than slats.

3) For further information on the application of solar energy in your state contact your county Extension agent or Extension Agricultural Engineer at your Land-Grant University.

PROJECT MANAGEMENT

Work on this project was performed by the University of Nebraska Department of Agricultural Engineering. Individuals directly involved were Gerald R. Bodman, P.E., Extension Agricultural Engineer--Livestock Systems (Project Manager) and Michael F. Kocher, Extension Assistant (Project Coordinator). Inputs from the Departments of Agricultural Economics and Animal Science are acknowledged.

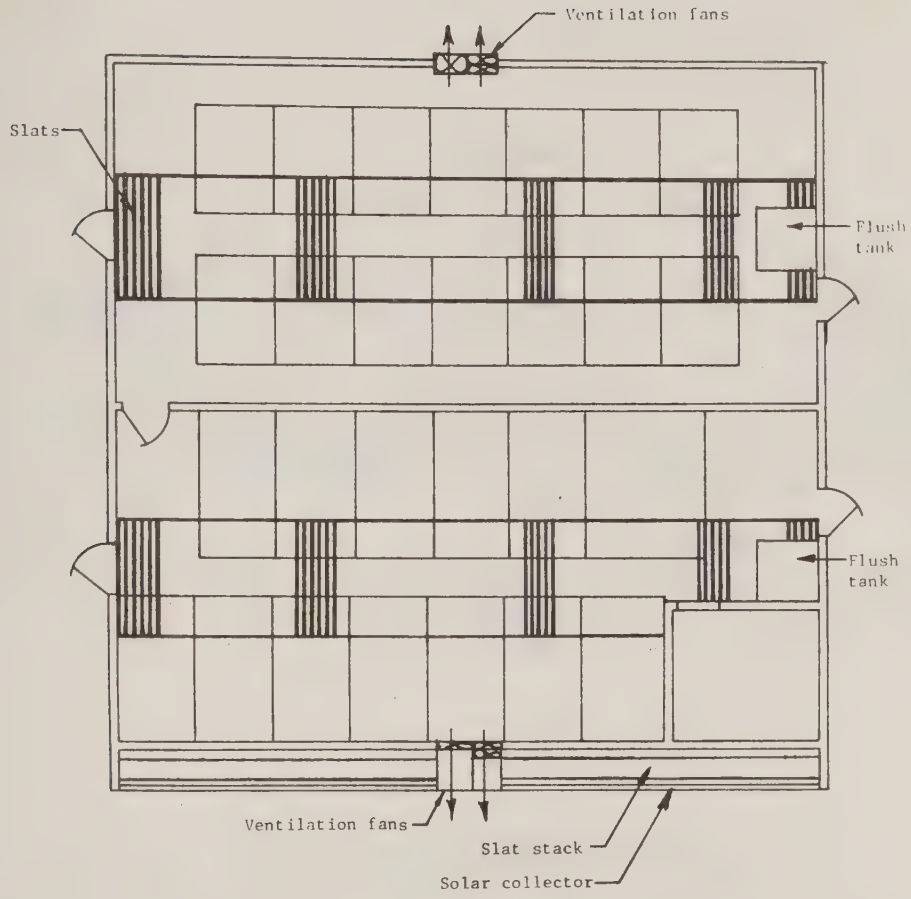


Figure 1. Building floor plan. (Menke). Details omitted for clarity.

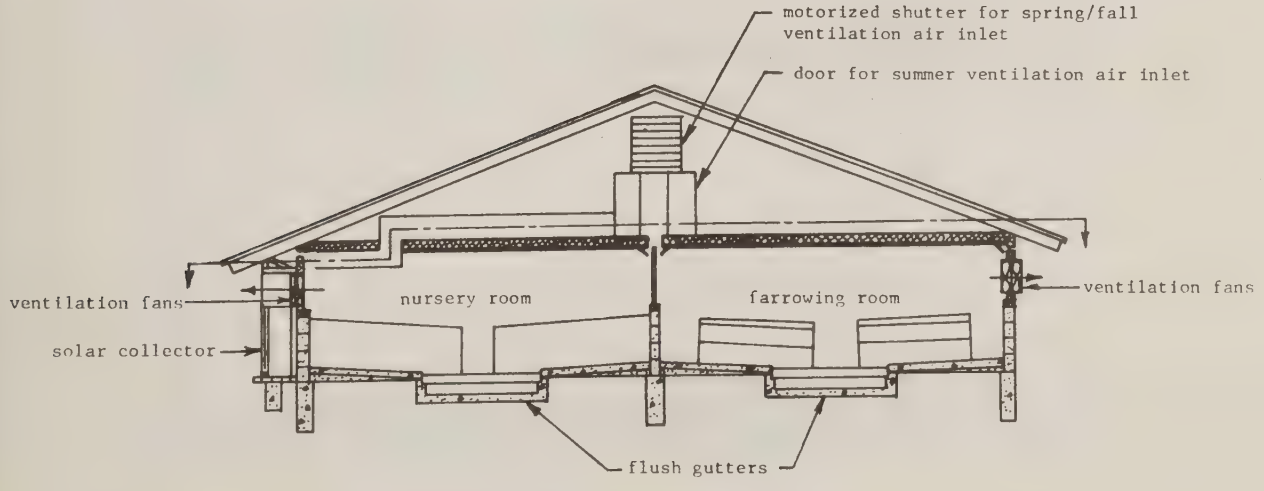


Figure 2. Building cross section (Menke). Details omitted for clarity.

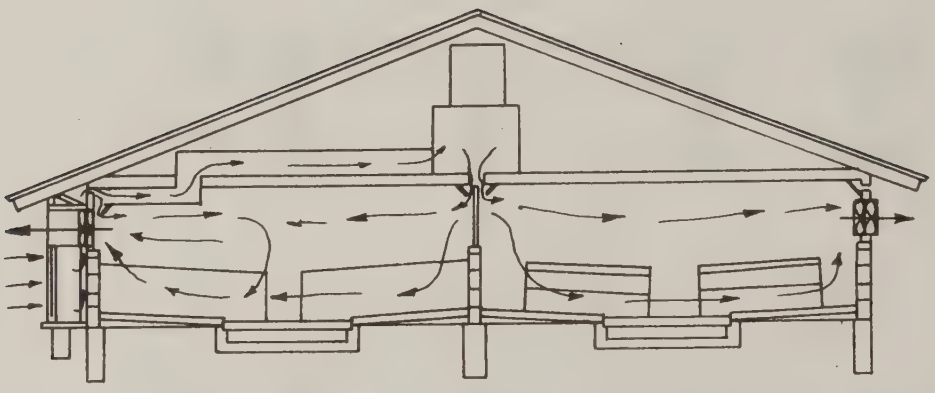


Figure 3. Cross section schematic of winter ventilation airflow paths (Menke). Details omitted for clarity.

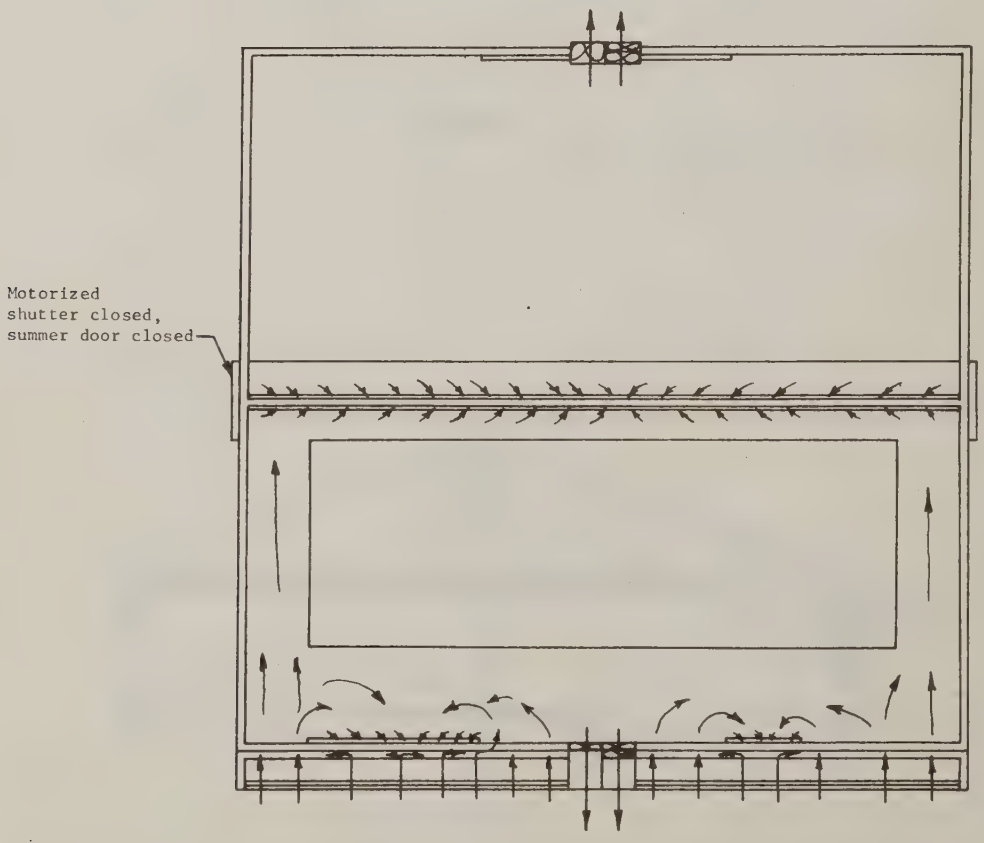


Figure 4. Floor plan schematic of winter ventilation airflow paths (Menke). Details omitted for clarity.

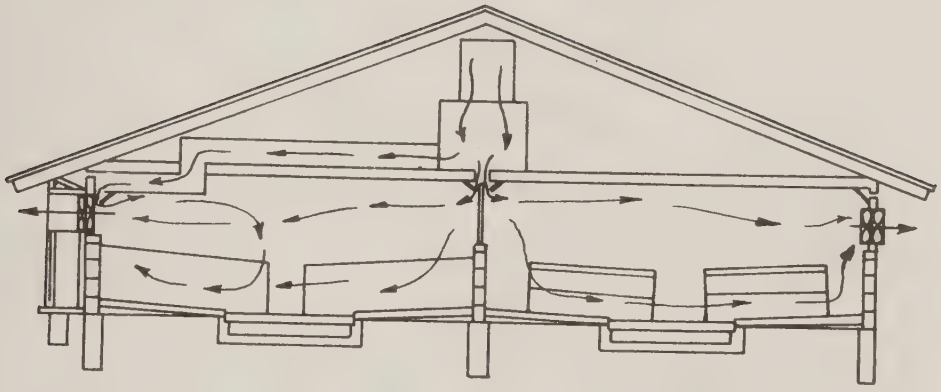


Figure 5. Cross section schematic of spring/fall ventilation airflow paths (Menke). Details omitted for clarity.

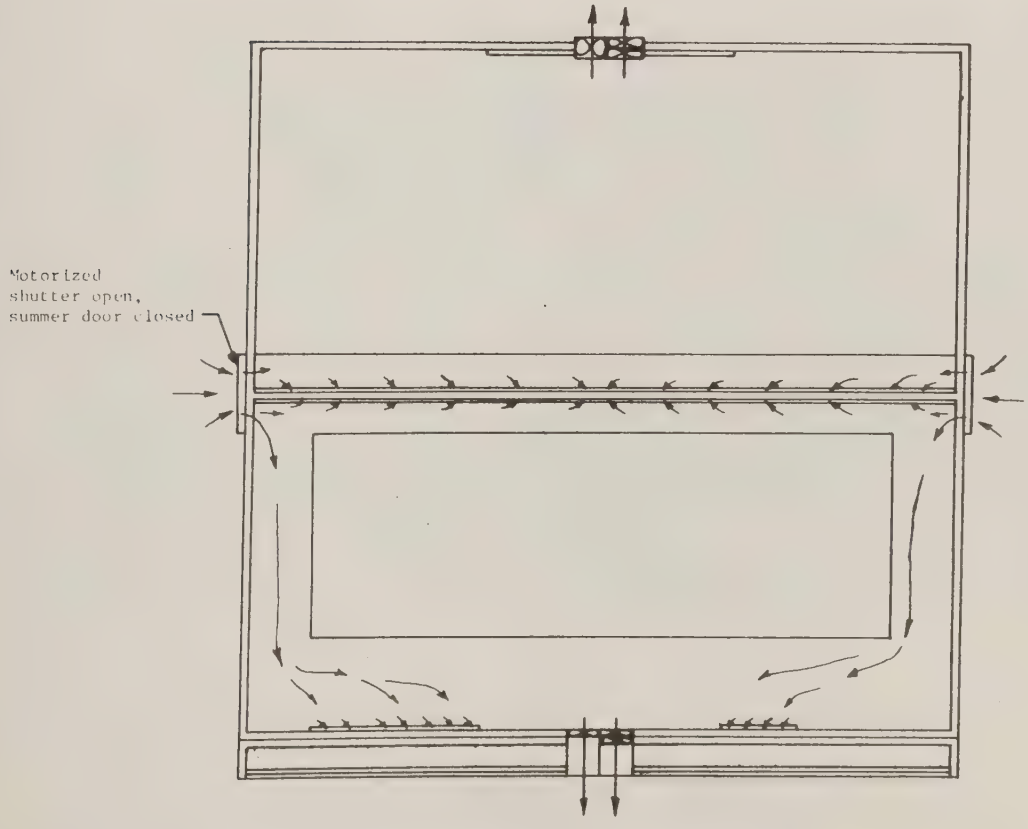


Figure 6. Floor plan schematic of spring/fall ventilation airflow paths (Menke). Details omitted for clarity.

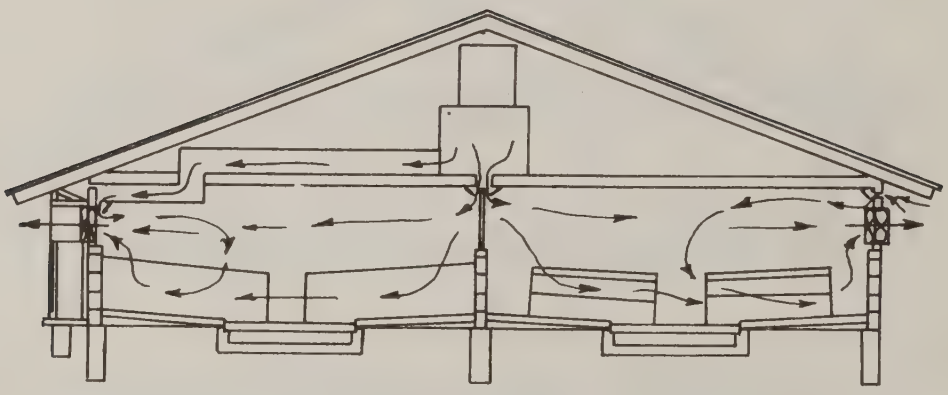


Figure 7. Cross section schematic of summer ventilation airflow paths (Menke). Details omitted for clarity.

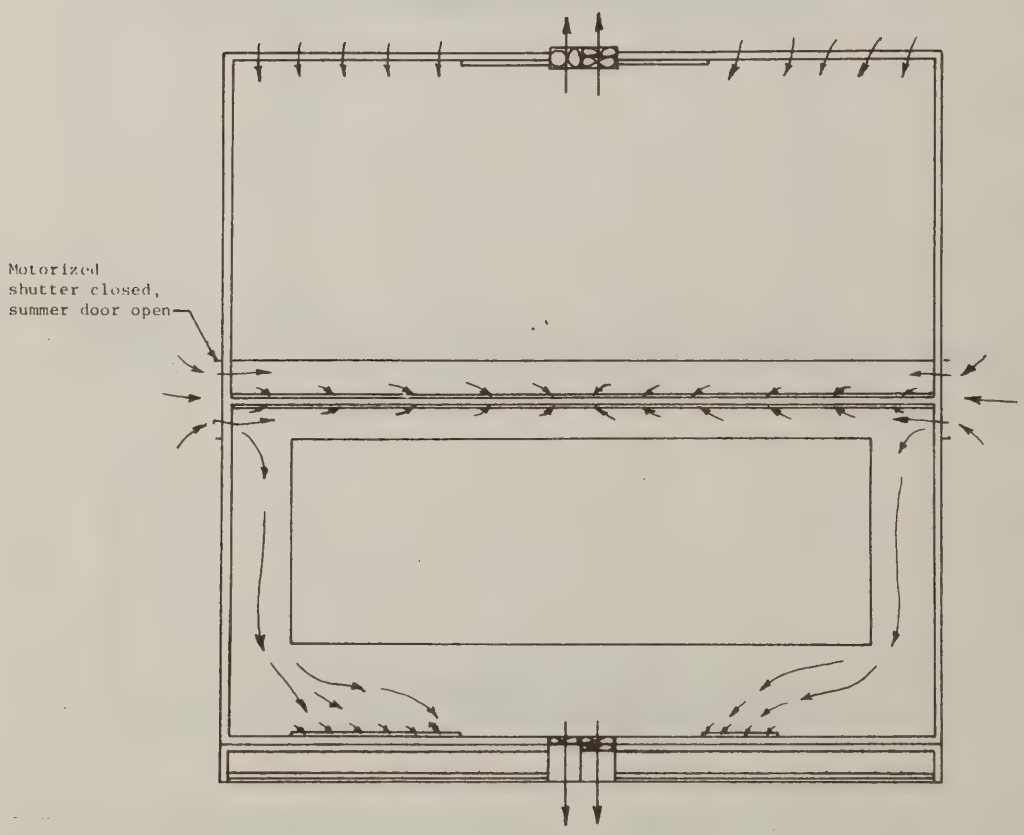


Figure 8. Floor plan schematic of summer ventilation airflow paths (Menke). Details omitted for clarity.

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SWINE NURSERY WITH VERTICAL SOLAR WALL

Galen Stevens
Creighton, NE

Demonstration Project
Solar Heating of On-Farm Livestock Structures
Project NE-8



200-head nursery building with a vertical solar collector for preheating ventilation air.

UNIVERSITY OF NEBRASKA-LINCOLN, COOPERATING WITH THE COUNTIES AND THE U.S. DEPARTMENT OF AGRICULTURE

The University of Nebraska-Lincoln The University of Nebraska Medical Center The University of Nebraska at Omaha

SWINE NURSERY WITH VERTICAL SOLAR WALL

Galen Stevens
Creighton, NE

THE FARM

Galen Stevens rents and operates the farm on which this demonstration facility is located. The farm (42°29'N, 97°46'W) is located in northeastern Nebraska's Knox County. Corn and alfalfa are grown on 225 and 30 acres of irrigated cropland, respectively. Corn and oats are grown on 75 and 100 acres of dryland, respectively. The livestock operation consists of a 40-cow herd cow-calf operation with calves fed out to market weight and an 80-sow farrow-to-finish swine operation with an annual production of 1100 market-weight hogs.

The Stevens have cooperated with the University of Nebraska, the U.S. Department of Agriculture and the U.S. Department of Energy in designing, constructing, instrumenting, and monitoring this system. Information in this report includes a description of the nursery building and the solar collector. Guidelines on constructing and operating the system, some system performance results and suggested system modifications are also included.

GOALS

The design of the solar collector system was governed by the following objectives:

1) The solar collector system must be designed to allow the farmer or farm builder to construct the system with as much locally available material and equipment as is technologically and economically possible.

2) The system must be understandable and manageable by the farmer.

3) The system must be designed so the farmer can reasonably be expected to make any necessary repairs.

SYSTEM DESCRIPTION

A. The Nursery Building

The 24 x 40 ft building contains two separate areas--a 33 x 24 ft nursery room and a 7 x 24 ft storage area at the east end (See Figure 1). Along the full south wall of the building is the 40 x 7 ft solar collector. The building has a gable roof and is mechanically ventilated using over-the-wall slot inlets for ventilation air. The ventilation fans are grouped together in a bank and centered on the north wall of the building. The floor in the nursery room is 100 percent woven wire above a manure storage pit (See Figure 2). The continuous operation winter ventilation fan and the thermostatically controlled spring/fall fan draw air from above the manure in the pit and exhaust the air from the building (See Figures 3 and 4). The summer ventilation fan draws air directly across the pig environment and exhausts the air from the building (See Figures 5 and 6). This arrangement provides for control of pit odors and gases at all times of the year while providing cooling during the summer.

B. The Solar System

The 280 ft^2 solar collector is a concrete block wall with two Filoplate® #556 (inner layer flat, outer layer corrugated) glazing layers (See Figure 2). The east 8 ft of the collector consists of concrete slats stacked with spacer bars between slat layers to provide horizontal gaps for airflow. The remainder of the collector consists of 6 x 8 x 21 in. (nominal) solid concrete blocks stacked with the long dimension perpendicular to, and 3 in. away from, the south wall of the building. This particular storage configuration was used because the owner had a few concrete slats left over that he wished to use in the collector and purchased the blocks to fill the remainder of the collector.

The south side of the concrete blocks and slats is painted black to increase solar energy absorption. This absorber surface is covered with the double-layer glazings. The blocks are dry stacked (no mortar) with vertical gaps left between adjacent blocks. These gaps allow airflow through the block wall. The slots and gaps in the collector glazings and blocks are designed so winter ventilation air (2.6 cfm per ft^2 of collector), enters the collector between the glazings, travels across the warm black surface of the block wall, filters through the gaps between the blocks and goes into the building through the ventilation air inlet. The ventilation fans exhausting moisture, gases, and odors continually pull ventilation air through the collector into the building (See Figures 3, 4, 5, and 6). In this way the building ventilation fans provide the power to move the air through the collector, thus eliminating the need for a separate fan to perform this function. The concrete blocks and slats act both as absorber plate and heat storage. When the solar heating system cannot provide all the heat required, backup heat for the nursery room is provided by a propane fired heater.

COST

The materials and labor cost for the collector system was $1,961.04 for 280 ft^2 of collector or $7.00 per ft^2 of collector area. This can also be calculated as $9.81 per pig space based on a 200-pig building capacity.

The materials cost for the building (without the solar collector) was $14,578. Labor costs were not recorded since the cooperator constructed the building. Assuming the cost for materials was 65 percent of the total building costs yields a building cost of $22,428 or $112 per pig. Including the solar collector brings the total building cost including labor and materials for the building and collector to $24,389. The solar collector system costs added 9 percent to the building cost.

PERFORMANCE

A. Thermal

The vertical solar wall provided 2.76×10^6 Btu of ventilation air preheating during 15 days in April 1982. For these same 15 days, with an average indoor ambient temperature of 84^0F and an average outdoor ambient temperature of 26^0F (range was -4 to 55^0F), the calculated heat requirement of the building was 6.82×10^6 Btu. Thus, the collector provided 40 percent of the heat required by the building during those 15 days.

A plot of the typical ventilation air preheating operation of the collector is presented graphically in Figure 7. The air leaving the collector and entering the building (collector outlet) generally has a higher temperature than the air entering the collector (outdoor ambient). The storage of solar heat is reflected in the temperature increase of ventilation air passing through the collector at night. At this time, solar heat stored during the day is released to the ventilation air, increasing the air temperature and decreasing the need for auxiliary heat.

On March 27, 1981, the outdoor ambient air temperature increased faster and peaked higher than the temperature of the air leaving the collector. At the point where the two lines intersect, all the solar heat is being stored in the thermal mass of the concrete storage. When the temperature of the air at the collector outlet is lower than the temperature of the collector inlet, some heat from the outdoor air passing through the collector, as well as all the solar heat, is being stored in the collector thermal storage mass. As the outdoor air temperature drops the thermal storage mass begins to release heat to the air passing through the collector, and the temperature of the air at the collector outlet returns to a temperature higher than that of the outdoor air.

B. Economic

Lack of sufficient data through an entire heating season does not allow accurate evaluation of the economic returns from this solar collector system. Returns from this collector are assumed to be equivalent

to returns from other vertical solar walls when calculated on a per ft^2 of collector area basis. This collector will probably not be able to supply the same annual percentage of required heat as collector systems operating at other locations in Nebraska because of higher indoor ambient temperature requirements for nursery buildings and lower outdoor ambient temperatures at this northerly location.

The normal heating season in this location is 6876 F°·days with a base temperature of 65°F. The overall exposure factor for the building is 1244 Btu/hr·F° , and the indoor ambient temperature for this nursery is generally kept at 80°F. The 200 pigs are assumed to generate 33,600 Btu/hr. The balance point temperature for this building is 53°F, reducing the normal heating season to 4058 F°·days.

With the 1244 Btu/hr·F° exposure factor and 4058 F°·day heating load, the annual building heating requirement can be calculated at 121 x 10^6 Btu. Assuming 40 percent of this load, normally provided by the propane furnace burning propane costing $0.56 per gal, the solar collector annually saves 702 gal of propane or $393. The $1961 collector cost divided by the $393 annual fuel savings yields a simple payback period of 5.0 years.

C. Maintenance

The solar heating system does require some maintenance. Regular monthly maintenance of the ventilation fans and equipment should keep the ventilation equipment operating properly.

Adjustment of the ventilation air inlet baffle positions is necessary to keep airflow through the collector and nursery at proper levels.

Maintenance of the collector exterior (except for glazings) is similar to maintenance of typical building exteriors. All wood must be kept covered with a good coat of paint to minimize weathering. Protect the collector from entry by rodents, birds, animals, termites, etc. Caulk all cracks to prevent cold air from entering the collector at improper locations.

Maintenance of the collector glazings may require washing the outside glazing in the fall. Keep all glazing joints properly caulked with a good quality clear silicone caulk. These glazings may need to be replaced after several (between 5 and 10) years.

D. Problems

Problems with the data logger-cassette tape interfacing mechanism prevented gathering data several times. The distance from Lincoln, NE to this site near Creighton, NE (about 200 miles) added to the difficulty in gathering data.

COMMENTARY

A. Construction Suggestions

1) Glazing materials for the collector should be chosen to withstand ultraviolet light degradation and have good solar energy transmittance characteristics. The glazings must be able to withstand the impact of icicles and snow that drop off the roof during winter.

2) Be sure to seal the collector carefully except where airflow is desired. This will ensure proper airflow through the collector. Air leaks at the wrong places cause serious adverse effects on collector performance. It is much easier to seal joints during construction than to repair air leaks. Use only high quality, long lasting caulking materials. Clear silicone caulk is recommended.

3) All air inlets to the collector should be covered with 1/2 x 1/2 in. wire mesh screening to prevent birds from entering the solar system and the building.

4) Provide enough overhang so rain and snow do not blow into the collector inlet.

B. Suggested Modifications

1) Use of standard quality butyl caulk at collector glazing joints resulted in cracks in the caulk, and resultant cold air leaks, after the first year of operation. Use of good quality clear silicone caulk is recommended for all glazing joints.

2) Use of a standard roofing nail with a thin neoprene washer did not allow proper compression of the glazing to the framing members supporting the glazing. Use of a roofing nail with a thick rubber washer (for example Fabseal® nail by Fabral) is recommended.

3) Other blocks may be substituted for the 6 x 8 x 21 in. (nominal) concrete blocks. When substituting other blocks, be sure to provide proper spacing between the blocks for airflow. Allow between 3 and 5 ft^2 of open area in the block wall per 1000 cfm of ventilation air.

4) The 6 x 8 x 21 in. (nominal) concrete blocks are made of a low density concrete. They do not meet the generally recommended storage mass to collector area ratio. Consideration should be given to alternative designs which provide 2 ft^3 of storage mass per ft^2 of collector area. The slat stack in the east end of the collector does meet the 2 ft^3 of storage mass per ft^2 of collector area. Availability of used slats locally might make the slat storage mass less expensive than concrete blocks.

5) For further information on the application of solar energy in your state contact your county Extension agent or Extension Agricultural Engineer at your Land-Grant University.

PROJECT MANAGEMENT

Work on this project was performed by the University of Nebraska Department of Agricultural Engineering. Individuals directly involved were Gerald R. Bodman, P.E., Extension Agricultural Engineer--Livestock Systems (Project Manager) and Michael F. Kocher, Extension Assistant (Project Coordinator). Inputs from the Departments of Agricultural Economics and Animal Science are acknowledged.

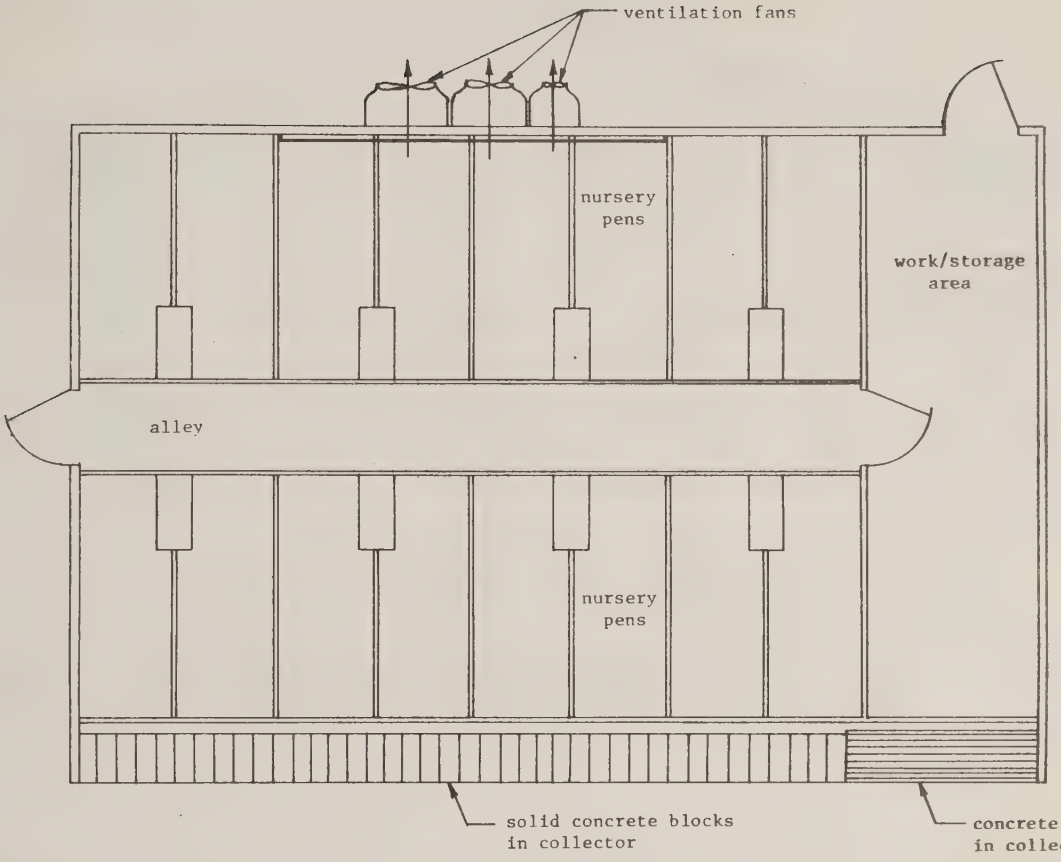


Figure 1. Floor plan of the 200 pig nursery (Stevens). Details omitted for clarity.

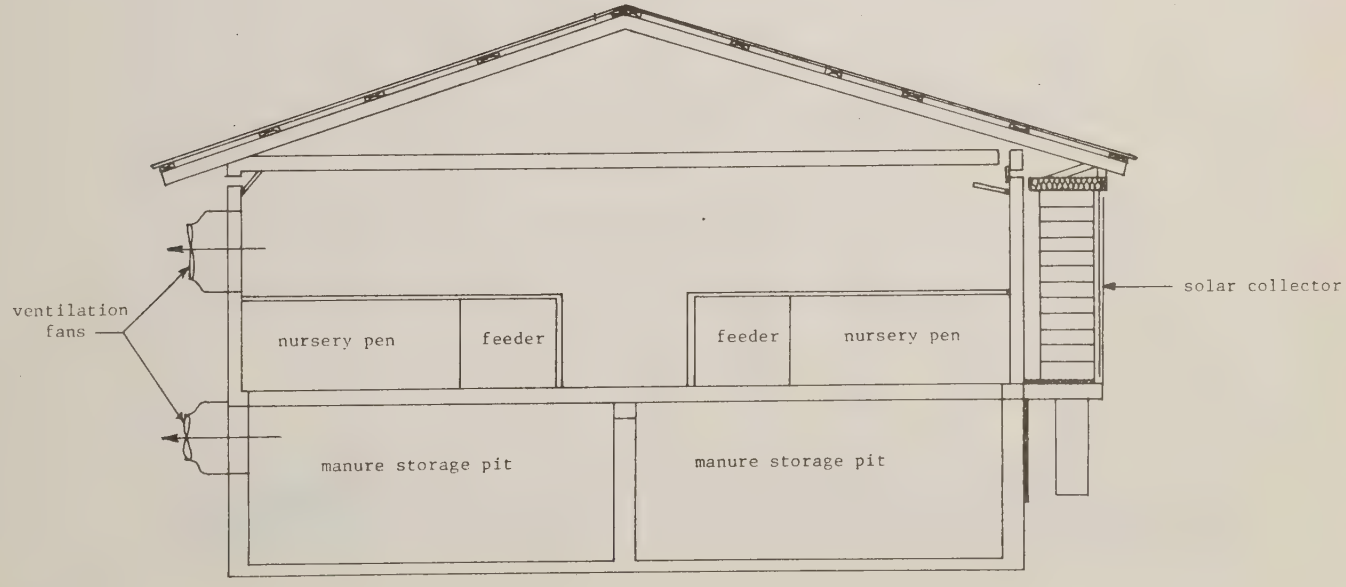


Figure 2. Cross section schematic of building (Stevens). Details omitted for clarity.

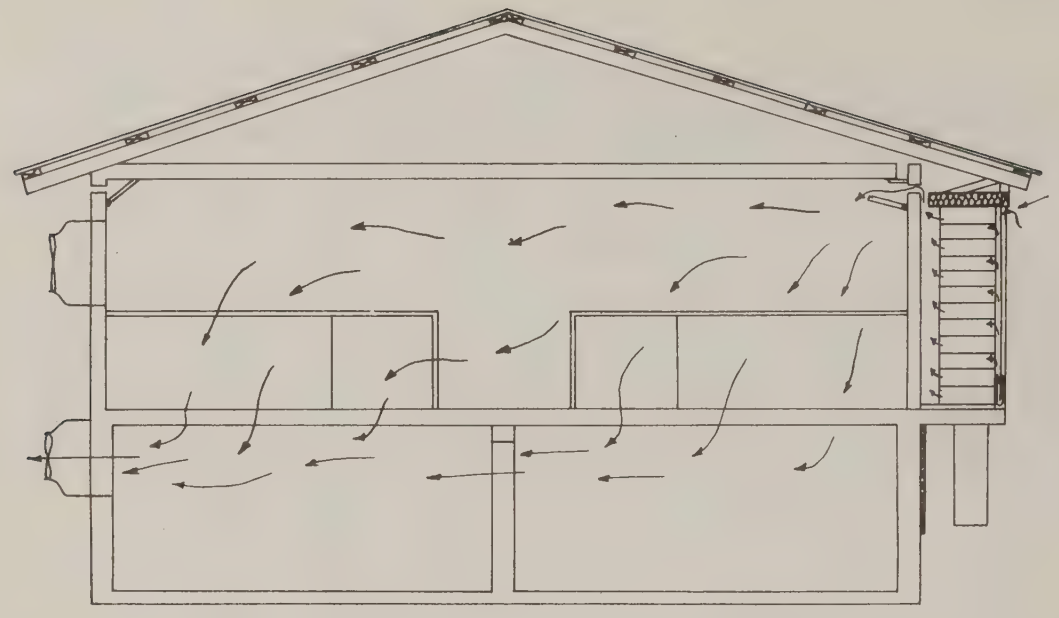


Figure 3. Cross section schematic showing winter ventilation airflow paths (Stevens). Details omitted for clarity.

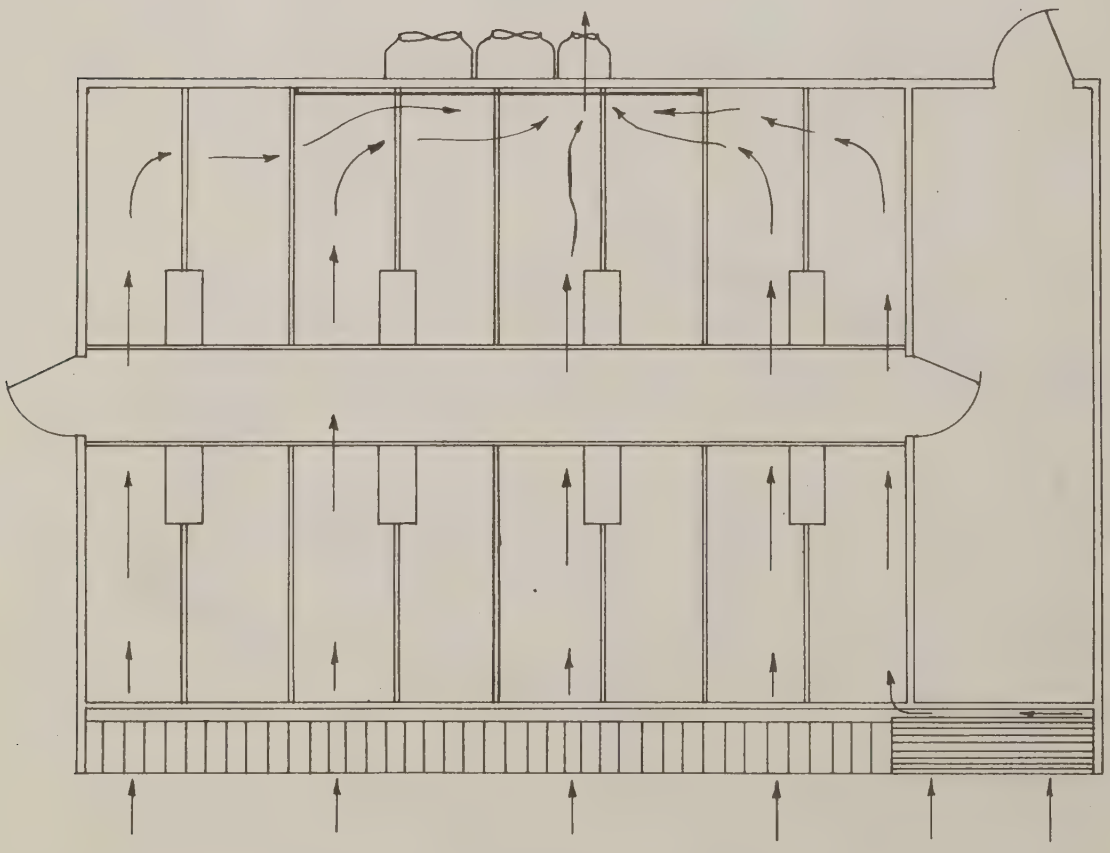


Figure 4. Floor plan schematic of winter ventilation airflow paths (Stevens). Details omitted for clarity.

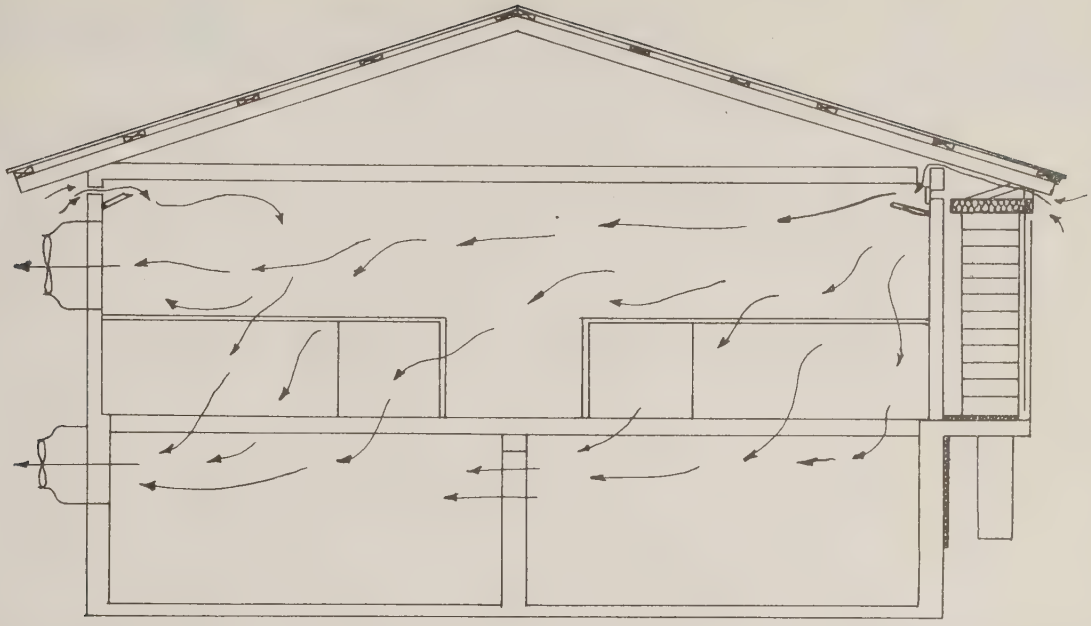


Figure 5. Cross section schematic showing summer ventilation airflow paths (Stevens). Details omitted for clarity.

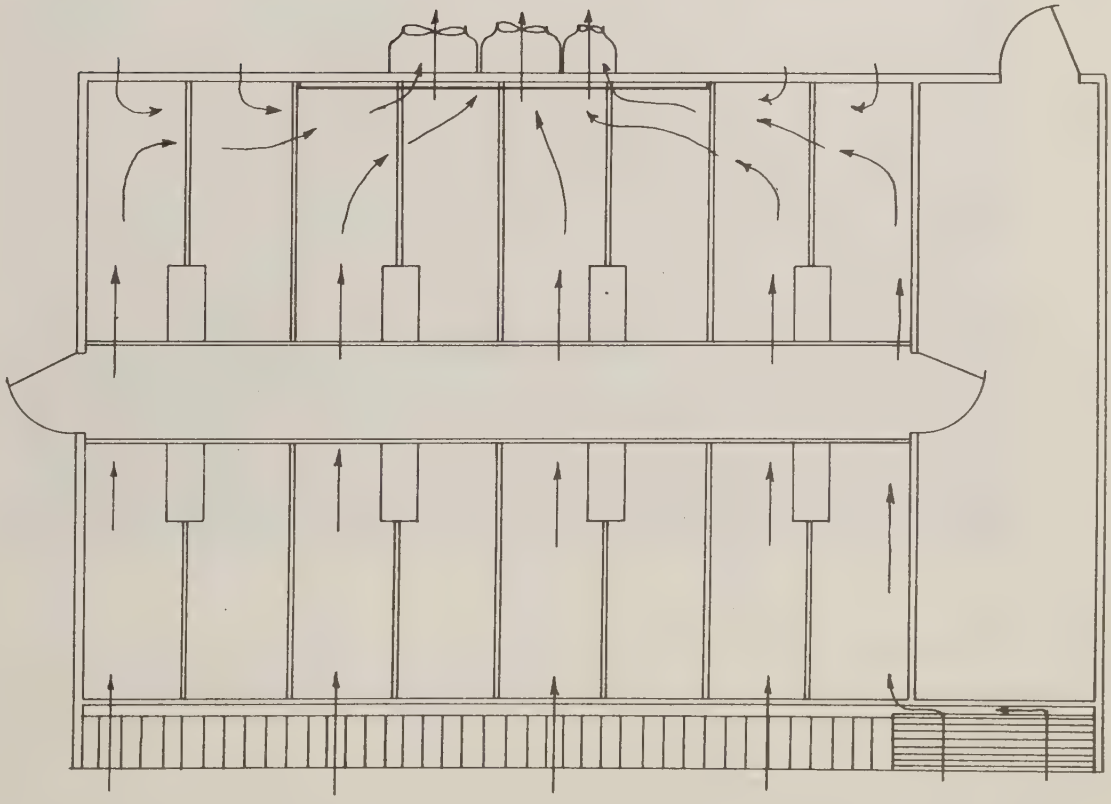


Figure 6. Floor plan schematic of summer airflow paths (Stevens). Details omitted for clarity.

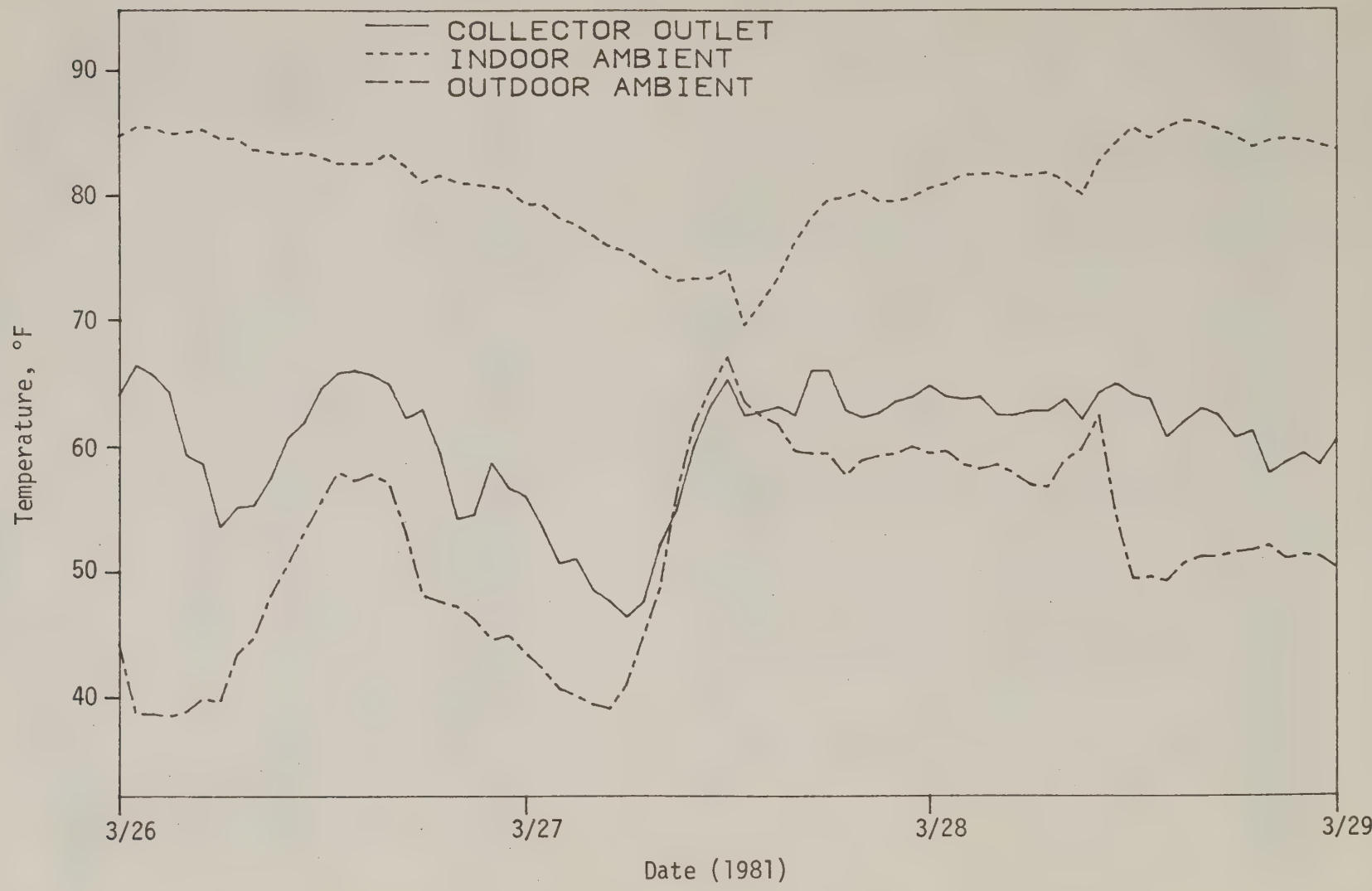


Figure 7. Nursery winter ventilation air preheating with a vertical solar wall. (Stevens)

Cooperative Extension Service
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MOF SWINE NURSERY WITH IN-FLOOR SOLAR HEAT

Ross Larson
Ceresco, NE

Demonstration Project
Solar Heating of On-Farm Livestock Structures
Project NE-10



300-head Solar MOF Nursery building with active/passive solar system and in-floor heat.

UNIVERSITY OF NEBRASKA-LINCOLN, COOPERATING WITH THE COUNTIES AND THE U.S. DEPARTMENT OF AGRICULTURE

The University of Nebraska-Lincoln | The University of Nebraska Medical Center | The University of Nebraska at Omaha

MOF SWINE NURSERY WITH IN-FLOOR SOLAR HEAT

Ross Larson
Ceresco, NE

THE FARM

Ross Larson rents and operates the farm with the recently added solar nursery. The farm (41°8'N, 96°40'W) is owned by Ross' father and is located in eastern Nebraska's Saunders County. The farming operation consists of growing milo and soybeans on 200 and 120 acres of dryland, respectively. Alfalfa is grown on 40 acres of dryland. The remaining 40 acres of the farm are used for pasture and the production of oats.

Ross has cooperated with the University of Nebraska, the U.S. Department of Agriculture and the U.S. Department of Energy in designing, constructing, instrumenting and monitoring this system. This report includes descriptions of the nursery and the solar collector system as well as the cost of the system. Some performance results, suggested modifications of the system and details on where to obtain plans for construction of a building similar to this one are presented.

GOALS

The design of the solar collector system was governed by the following objectives:

1) The solar collector system must be designed to allow the farmer or farm builder to construct the system with as much locally available material and equipment as is technologically and economically possible.

2) The system must be understandable and manageable by the farmer.

3) The system must be designed so the farmer can reasonably be expected to make any necessary repairs.

SYSTEM DESCRIPTION

A. The Solar Nursery

The 12-pen 300-head nursery unit incorporates several energy conserving features besides the solar heating system. The 23 x 60 ft building has a mono-slope roofand is non-mechanically ventilated and well insulated (See Table 1 for recommended R values). The building uses in-floor heat for zone heating--heating the floor and allowing the warm floor to heat the pig's immediate environment. Insulated hovers are used to help keep the majority of this heat down in the pig's environment. The in-floor heat and insulated hovers are located in the rear 40 percent of each pen. Feeders in the pen partition walls are located in the middle portion of each pen. Manure is removed from the building via an open flush gutter system located along the south end of the pens. Flush water control is provided by a dosing siphon flush tank (See Figure 1).

B. The Solar Collectors

Supplemental heat for the nursery building is supplied by a combination of active and passive solar collectors. The double glazed passive collection system consists of 3 ft windows at the top of the south wall. Solar energy passing through these windows is absorbed by the 3 in. thick concrete floor which is insulated from the underlying soil. Two sets of doors, one 3 ft high and the other 18 in. high, beneath the passive windows are openable for ventilation. The sills of the lower of these doors (18 in. high), are approximately 4 ft above exterior grade level, allowing room for the active collector below them. The single-pass, 3 ft-3 in. x 50 ft collector is sloped 60 degrees from the horizontal to allow maximum winter solar energy collection. The active collector heats air which travels through the collector (approximately 2.0 cfm per ft^2 of collector), through the heat distribution-storage part of the floor and returns to the collector in a closed loop arrangement (See Figure 2).

The In-Floor Heat Distribution-Storage (IFHDS) system for the active collector system consists of concrete blocks laid on edge with the cores aligned to provide air channels along the length of the building. The heat storage is five 8 x 8 x 16 in. (nominal) blocks wide, with a 7 to 10 in. sand layer above the blocks, and a 3 in. concrete floor above the sand. This heat storage is insulated to prevent excessive heat loss to the surrounding soil. The resultant storage capacity is approximately 2 ft^3 of storage per ft^2 of collector.

Black polyethylene water lines positioned in the sand layer allow heat to be added to the IFHDS system from water heated by a boiler (See Figure 3). This fossil fueled auxiliary heating system was added to the system design because of plans to place 3-week old, early-weaned pigs weighing approximately 10 to 12 lbs directly into this facility. (Note: Results from the NE-1 demonstration project have shown that during normal winters a fossil fueled backup heating system is not needed for 20 lb pigs. The backup system was installed at Larson's to ensure maintenance of a constant floor surface temperature for the lighter weight pigs.)

C. Non-Mechanical Ventilation

The non-mechanical ventilation system is another energy-saving feature of the nursery. Winter ventilation is achieved through adjustment of the lower set of small openable panels and an air outlet near the top of the south wall. The larger openable south wall panels in combination with openable panels and an eave vent along the north wall facilitate increasing airflow through the animal space during warm weather. Airflow under all weather conditions is augmented by the 3:12 roof slope.

COST

The active collector and the heat storage added a total cost (materials and labor) of $5509.33 to the cost of the building. With a collector area of 182 ft^2, this translates to $30.27 per ft^2 of collector area. Based on a 300-pig building occupancy rate, this cost can be presented as $18.36 per pig for the solar heating system.

This collector cost of $30.27 per ft^2 of collector area is higher than the $11.98 per ft^2 of collector area cost reported for a very similar building in the NE-1 project. This increase in cost can be attributed to several factors. One of these factors is the time difference of two years between construction dates, allowing inflation to affect the collector costs. Great care was taken by the contractors in constructing the IFHDS system to ensure that this part of the system will remain in optimum operating condition. This increased care led to increased cost. The third factor affecting the price increase for the construction of the collector is the presence of system parts that are not greatly affected by changes in the collector length. Examples are the under-floor air ducts(PVC pipes) at each end of the building between the collector and the IFHDS system and the fan and associated controls.

The cost of the complete solar nursery was $25,970, including the solar heating system. This cost represents an investment of $86.57 per pig. If the solar collector system had not been installed in the building, a $420 propane-fueled space heater would have to be purchased and a 500 gal propane storage tank purchased ($725) or rented. Assuming purchase of the propane tank and the space heater, the building could have been constructed with fossil fuel heat for $21,606. The difference between the costs of the solar and conventionally heated units is $4364. This represents a 20 percent increase in costs for the solar heating system.

PERFORMANCE

A. Thermal

Ross has been pleased with the performance of the building. Initial performance for this first winter of operation was satisfactory, although the solar collector system did not provide all the heat required to

keep the building warm. This is because the building was not completed until early fall and was not stocked to design capacity until mid-winter. About 200 pigs were moved into the building on October 14, 1981. This compares with the 300 pigs required for full capacity.

The winter of '81-'82 was also a cold winter, with the fourth coldest January in over 100 years of weather records (See Table 2). Below normal insolation levels during this winter also contributed to the heat from the solar collector system not meeting the heat requirements of the building. The percent possible sunshine for October was 75 percent of normal. With lower than normal solar insolation and a reduced quantity of heat available from the pigs, the floor surface temperature in pen 2 was only about 60°F on November 4, 1981 (See Figure 3). On November 5, 6, and 7, the solar collector added heat to the IFHDS system and the floor surface temperature rose to about 71°F.

On these dates the temperature of the air within the IFHDS system air passageway below pen 2 was lower at nighttime than below pen 8. At this time there were no pigs in pen 2, so no heat from the thermal interaction between the pigs and the floor surface was available to help maintain floor surface and IFHDS system temperatures. Pen 8 was stocked with 30 to 40 lb pigs that gave off reasonable amounts of heat as they interacted thermally with the IFHDS system. Heat from these pigs helped keep the air in the IFHDS system below pen 8 about 10F° warmer overnight than air below pen 2, even though pen 8 received less heat from the active solar collector system during hours of collector fan operation.

In November of 1981, the temperature of the air leaving the solar collector regularly peaked at about 178°F on sunny days (See Figure 5). The temperature of the air entering the collector during this same time period normally peaked at about 75°F. Concurrently outdoor temperatures were between 35 and 65°F and indoor ambient temperatures were between 60 and 75°F.

Temperatures under the hovers in the pens averaged approximately 10F° warmer than the temperature 5 ft above the floor in the feeding areas of the pens. This demonstrates the advantage of hovers and in-floor heat in energy savings since the whole building interior need not be heated to the high temperature required by the young pigs. This design reduces conductive heat losses through building surfaces while meeting the thermal needs of the young pigs. The use of hovers over the heated floor, a cooler open feeding area, and a cooler flush gutter area also allowed pigs to choose between three micro-environments to fit their thermal needs.

Although the auxiliary heating system involving the boiler and the water lines in the IFHDS system was never completed, two other auxiliary heating systems provided heat to the building during this first winter of operation. Heat lamps (250W) were placed in the 4 pens that had the smallest pigs. A space heater was also used to keep indoor ambient temperatures above 50°F.

It is not known whether all of the heat supplied by the solar system was needed at the time it was delivered to the floor surface. If excess

heat was added to the building by the solar heating system it was removed from the building with increased ventilation. With a non-mechanically ventilated building, accurate comparison of the supplied solar heat and heat actually required is not possible.

B. Animal

Pig performance in the nursery has been very good. The worst performance was a feed conversion ratio of 2.33 lb feed per lb of gain with a 0.69 lb per day weight gain. The best performance was a 1.85 lb feed per lb of gain with a 0.77 lb per day weight gain. These ration tests plus a death loss of less than one percent indicate the high level of pig performance.

C. Economic

An engineering heat balance was performed for this building for normal winter conditions. Estimated annual heating costs were $840 if petroleum-based fuels and conventional whole-building space heating techniques were used. This cost is based on a propane price of $0.56 per gallon.

During the winter of 1981-82, 7545 kWh of electricity at $0.033/kWh were used for the heat lamps. Seventy-eight gal of kerosene at $1.00 per gal were used in the space heater. The total cost of the auxiliary heat came to $327.

Assuming the $840 per year conventional heating costs and using the $4364 extra cost for all of the solar components above the cost of the conventionally heated building and an annual auxiliary heating cost with the solar collector of $327, the simple payback period can be calculated at 8.5 years. This payback period presents an extreme. It is anticipated that during a normal winter the auxiliary heat required for these small pigs could be provided by 6 - 40W light bulbs operated for six months. This represents 1051 kWh or about $35. Therefore, with an annual savings of $805 and an initial investment of $4364, the simple payback period drops from 8.5 years to 5.4 years. With tax credits, consideration of interest, inflation and the time-value-of-money approach to calculating life cycle costs, the payback period of this system should be very reasonable.

D. Ventilation System

All ventilation openings are manually adjusted. Openings are usually adjusted as needed during morning and evening checks of the facility and animals. The manually adjusted openings in combination with the three micro-environments within each pen have served to allow ventilation rates to be varied to meet the needs of various size pigs.

Adjustment of the south wall winter ventilation panels is accomplished by hand adjustment of the panel position. A friction-fit hinge maintains panel position after adjustment. The summer ventilation panels in the south wall can be adjusted by moving individual panels and placing hooks provided at each end of the panel through links in chains hanging from the ceiling.

The air inlet along the top of the south wall stays open except for extreme winter weather. North wall panels are opened and closed as necessary during the summer. The inlet vents at the top of the north wall can be opened and closed as necessary for increased ventilation during mild weather.

E. Maintenance

The solar heating system does require some maintenance. Dust must be washed off the active collector glazings about once per month, especially when peak solar heating is required (i.e., when a group of newly weaned pigs is moved into the building). The solar collector fan bearings must be greased and belt tension checked. Glazings must be checked for damage after bad storms or, just generally, about twice per year. The active collector must be covered at the beginning of the summer to prevent overheating the building and the collector. The collector must be uncovered about 2 weeks before heat is needed in the nursery. This allows the solar collector to "charge" the IFHDS system. The wood on the exterior of the collector should be kept protected with paint to reduce the effects of weathering. Joints in the solar collector system should be inspected at least annually to be sure they are tightly caulked to prevent air leaks. Attempts by rodents to enter the system must be repaired.

F. Problems

A particular problem with this facility was the failure of the thermostat that controlled operation of the fan in the active solar collector system. Lack of the ability to replace this thermostat led to manual control of the collector fan operation. Data have shown that this manual operation is far inferior to automatic operation. Starting the fan before the collector air temperature was high enough to deliver heat to the IFHDS system resulted in a heat loss from the IFHDS system. One hour of fan operation before the collector air temperature was high enough to deliver heat to the IFHDS system required 2 to 4 hours of proper collector operation to offset the heat loss. Therefore, two or three hours of poorly timed fan operation in the morning and afternoon can cancel all the benefits of heat gained from an entire day of proper collector operation. Manual control of the fan operation is <u>not</u> recommended, while automatic control (thermostat with a remote sensing bulb) is felt to be essential.

Hovers placed 3 to 6 in. above the backs of the pigs in the first 6 of 12 pens allowed the pigs to jump up and crawl around on top of the hovers. Hovers were raised to the top of the pen divider walls (approximately 3 ft above the floor) and a flap at the front end of the hover added to keep heat trapped under the hover. This hover construction technique made it dark under the hovers and pigs soon began to dung in this area. Placement of heat lamps in the top of the hover lighted the area under the hover so that the pigs began to dung in the flush gutter. It is recommended that 40W light bulbs be used instead of heat lamps unless the auxiliary heat is required. This problem of darkness and dunging under the hovers did not occur at the Paus nursery (NE-1). We believe the large (3 ft high) panels in the south wall should be glazed as at the Paus'

nursery rather than made into an insulated panel as was done at Larson's. This should let enough daylight into the building to keep the area under the hovers lighted well enough to prevent the incorrect dunging pattern.

One problem with the active solar collector system, noticed from the data early in the project, was a large temperature drop (28 to 35F°) in the solar heated air between the outlet from the collector and the inlet to the IFHDS system. A similar temperature drop was noticed at the inlet end of the collector. These problems occurred during collector operation. A door in the outlet end of the collector to allow access to the collector for instrumentation, inspection, etc. was caulked shut to reduce air leaks. This measure reduced the large temperature drop but did not completely solve the problem. We believe increasing the level of insulation from R 4 to R 15 for all surfaces of the transition boxes between the solar collector and the PVC pipes will reduce the temperature drop at these locations to a reasonable level of about 10F°. Be sure to use a high temperature insulation in these locations.

Other problems noticed from the data were gradual overnight temperature decreases at the active collector inlet and outlet, and at the inlet and outlet of the IFHDS system. These temperature drops occurred overnight, whereas the previously mentioned problem occurred while the collector was operating. These overnight temperatures decreased towards the outdoor ambient temperature with the collector outlet temperature between the floor inlet (air passageway, pen 2) and outdoor ambient temperatures (See Figure 6). We believe natural convection currents at each end of the building are set up by the density differences between the warm air at the IFHDS system and the cold air at the collector. The convection currents are causing the temperature decreases in the air at the IFHDS system. To prevent these convection currents and the associated heat loss from the IFHDS system, we recommend placing back-draft dampers at the outlet ends of the PVC pipes. The recommended back-draft dampers are pieces of plastic that can withstand temperatures as high as 200°F (See Figure 7). A layer of high temperature fiberglass insulation should be attached to the plastic sheet to reduce conductive heat transfer from the air in the IFHDS system to the air in the PVC pipes during these overnight periods.

COMMENTARY

A. Construction Suggestions

1) Plan No. NE 10.726-37 Solar MOF Nursery is available from the University of Nebraska Agricultural Engineering Plan Service for $5.00 and provides the information needed to construct one of these buildings. The plan packet includes guidelines regarding construction techniques and materials, solar energy, equipment selection and system management.

2) One specific construction procedure is to completely seal the active collector system against air leaks during construction.

Collector performance is highly dependent on having an airtight system. It is much easier to build properly the first time than to repair air leaks. Use only high quality, long life caulking materials. Clear silicone caulk is recommended.

3) Glazing material for the collector should be chosen to withstand ultraviolet light degradation and to have good solar energy transmittance characteristics.

4) If Tedlar® is used as glazing care should be taken to prevent creasing of the Tedlar® during construction of the active collector. The Tedlar® will crease if a heavy object is laid on a fold. The creases are weaknesses in the Tedlar® sheet and tearing might occur as the Tedlar® shrinks in very cold weather.

5) Installation of the Tedlar® collector glazing with a clear silicone caulk adhesive and nailers are recommended over installation with an adhesive transfer tape. The tape was tricky to use, and is therefore not recommended.

6) Install the fan and back-draft dampers in a manner that allows for servicing and repair. The fan and transition should be placed in an "empty pen" to allow easy access, proper heat delivery to the floor of the first pen with small pigs, and space for equipment storage.

7) Use a high temperature fiberglass insulation board in the active collector behind the absorber place to prevent "failure" of this insulation. Plastic foam insulations in this location will "melt". Normal fiberglass insulation in this location will experience decomposition of the organic binder or "glue" holding the fibers together. This decomposing binder will give off a gas that will "cloud" the inside of the glazing and reduce transmittance of solar energy to the absorber plate.

8) Placement of the fan to provide a suction at the collector outlet is recommended. In this arrangement, any leaks would allow cold air into the collector. Alternately, with the collector under pressure from the fan, a leak near the collector outlet could result in warmed air being pushed outside. Cold air leaking into the collector is more easily detected with temperature sensing equipment in the collector than is warm air leaking out.

9) With the recommended fan placement, the fan must be constructed so that its motor is remote from the airstream. Hot air from the collector will be passing through the fan, but most electric motors are not built to take the high temperatures from these solar collectors. A belt driven fan is almost mandatory in this situation.

10) Automatic control (thermostat with remote sensing bulb) of the solar collector fan is highly recommended. Manual control of

the solar collector fan in this unit has been unsatisfactory since two to three hours of fan operation at the wrong time can cancel benefits of heat gain from an entire day of proper collector fan operation. The remote sensing bulb for the thermostat that controls the collector fan should be located in a shady spot near the collector outlet. The suggested location is in the upper half of the collector height and one to two inches from the edge of the solid cover used to form the transition.

11) When building the transitions from the collector to the PVC pipe (or equivalent) air ducts, and from the air ducts through the fan to the concrete blocks, be sure to insulate the transitions well. Insulation at these locations will reduce heat loss and prevent the fan motor from being overheated. High temperature insulation should be used.

B. Suggested Modifications

1) The ventilation openings along the top of the south wall must be equipped with baffles or other devices to allow partial closure during extreme winter weather. The closure devices are especially needed during periods of low temperatures and strong north and south winds. North winds tend to over-ventilate the nursery by drawing warm air out the openings while south winds force excess amounts of cold air in through the openings.

2) Use back-draft dampers at the outlet ends of the PVC pipe air ducts to prevent convection currents removing heat from the IFHDS system at night. A small flap of plastic (See Figure 7) can act as a gravity shutter to provide this back-draft damper. The plastic used for this flap must be able to withstand the 200°F temperature air from the collector. Attach a piece of high temperature insulation to the plastic sheet to reduce conductive heat losses. Cut the ends of the PVC pipe air ducts at an angle to provide a plane surface on a slope against which the damper can fall. Smooth the end of the pipe after cutting to increase the probability of a tight fit between the damper and the end of the pipe. Place beads of silicone caulk between the 2 x 4 in. (nominal) block and plastic flap, and plastic flap and nailer, to provide a good "hinge" for the damper. Use 3/16 in. diameter stove bolts and fender washers to fasten the insulation to the plastic flap. Place silicone caulk between the fender washers and the plastic flap and between the insulation and the plastic flap around the holes for the stove bolts to reduce stress concentrations and places where the plastic can tear.

3) The optimum collector and IFHDS system length seems to be in the 50 to 75 ft range. Multiples of these lengths are suggested for longer buildings with small pigs in the 15 to 30 lb category.

4) Buildings with lengths of 100 to 150 ft with pigs ranging from 15 to 50 lbs may need only one 50 to 75 ft active collector and solar IFHDS loop. The smaller pigs may be kept above the solar IFHDS system. The smallest pigs should be kept in the pens where the air in the solar IFHDS system is warmest (i.e., pens closest to the place where the hot air from the collector enters the solar IFHDS system). As the pigs grow they should be moved through the building towards the area where the air in the solar IFHDS system is cool (i.e., pens closest to the place where the air leaves the solar IFHDS system and returns to the collector). The rest of the building need not have the active collector system but research results indicate heat storage may be beneficial. This insulated thermal storage can be identical to the solar IFHDS system except the concrete blocks are not needed because no air will pass through this heat storage. The insulated thermal storage mass will help store heat released from the animals at night as they lie on this storage area. Some of this heat is slowly released to the air during the day. The remainder of the heat stored in this area is used to maintain or slightly increase the average floor temperature above this heat storage. The research data referred to herein were reported in a technical paper (No. 80-4514) of the American Society of Agricultural Engineers.

5) Provisions to allow installation of heat lamps above the sleeping area in one-fourth of the pens is recommended. These heat lamps should be provided for the pens in which the smallest pigs will be located(i.e., closest to the place where hot air from the collector enters the solar IFHDS system) on an "as needed" basis.

6) Caution should be taken in constructing a unit of this design in locations outside Nebraska. Certain features may need to be modified to accommodate local climatic conditions. For further information on the application of solar energy in your state contact your county Extension agent or Extension Agricultural Engineer at your Land-Grant University.

PROJECT MANAGEMENT

Work on this project was performed by the University of Nebraska Department of Agricultural Engineering. Individuals directly involved with the project were Gerald R. Bodman, P.E., Extension Agricultural Engineer--Livestock Systems (Project Manager) and Michael F. Kocher, Extension Assistant (Project Coordinator). Inputs from the Departments of Agricultural Economics and Animal Science are acknowledged.

Table 1. Recommended types and levels of insulation for the Nebraska Solar MOF Nursery (Larson).

Insulation Location	Insulation Type	Insulation Level
Ceiling/roof	Fiberglass batt	R-19
Stud wall	Fiberglass batt	R-11
Insulated concrete sandwich panel	Rigid foam board	R-13
Foundation perimeter	Extruded foam board	R-8
Beneath feeding floor	Extruded foam board	R-4
Around IFHDS system	Extruded foam board	R-8
Around solar collector air ducts	Fiberglass batt	R-11
Behind solar collector absorber plate	High temperature fiberglass*	R-8
Transitions between air ducts (PVC pipe) and collector outlet	High temperature fiberglass*	R-15
Transition between air ducts and fan	High temperature fiberglass*	R-12
Transition between fan and IFHDS system	High temperature fiberglass*	R-12
Outlet end of air ducts (backdraft damper)	High temperature fiberglass*	R-4

*High temperature fiberglass is necessary to prevent this insulation from degrading at the temperatures attainable in the collectors.

Table 2. Weather data near the Larson unit.

	1981			1982		
	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.
Average monthly temperature, °F	51.5	42	26.5	16.5	27	38
Departure from normal average monthly temperature F°	-3	3	-2.5	-10.5	-4.5	0
Heating degree days, F°. days	420	684	1185	1504	1064	832
Normal heating degree days,[1] F°. days	326	780	1163	1302	1078	837
Percent possible sunshine[2]	50	57	39	40	61	50
Normal percent possible sunshine[1]	67	57	52	57	59	59

Source: NOAA Climatological Data for Nebraska for the weather station at Wahoo, NE, 8 miles northeast of the unit

[1] Taken from Climatic Atlas of the United States, 1968.

[2] NOAA data for the weather station at the airport in Lincoln, NE, 15 miles southwest of the unit.

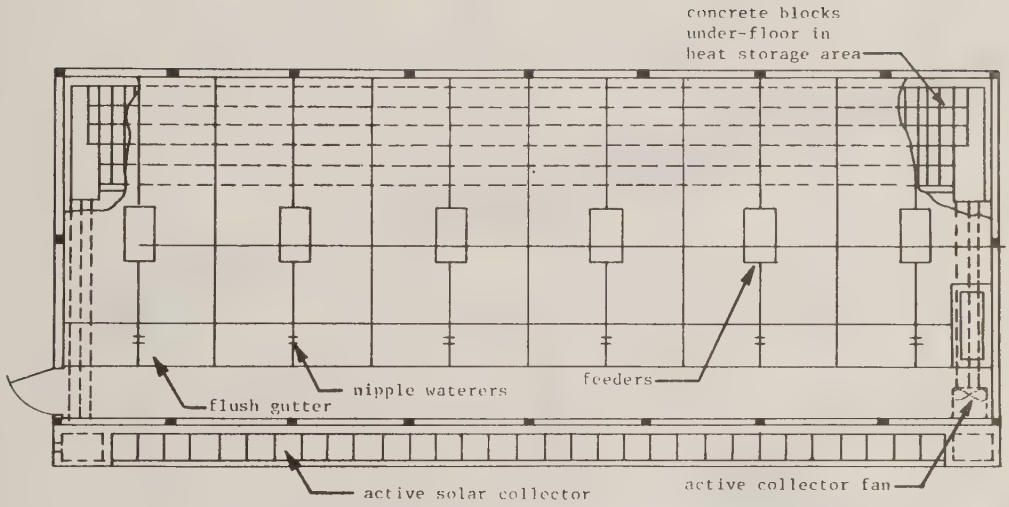


Figure 1. 300 pig Solar MOF Nursery floor plan (Larson). Details omitted for clarity.

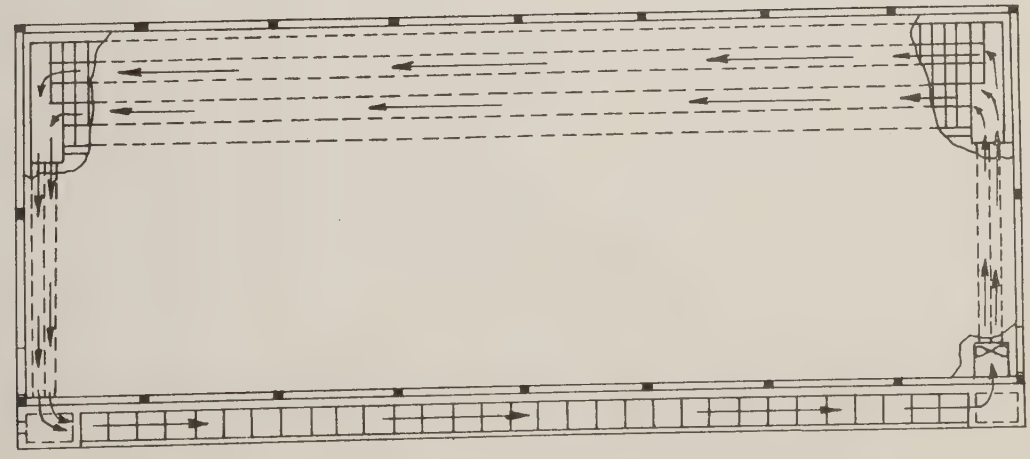


Figure 2. Fluid flow through the active solar collector and storage system (Larson). Details omitted for clarity.

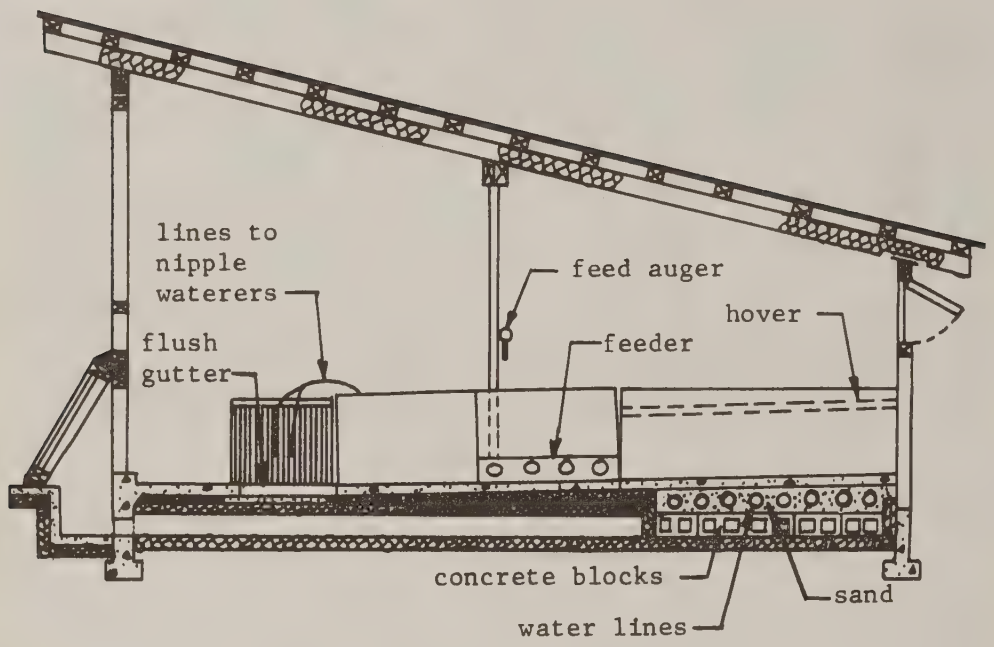


Figure 3. Cross section schematic of the solar modified open front nursery (Larson). Details omitted for clarity.

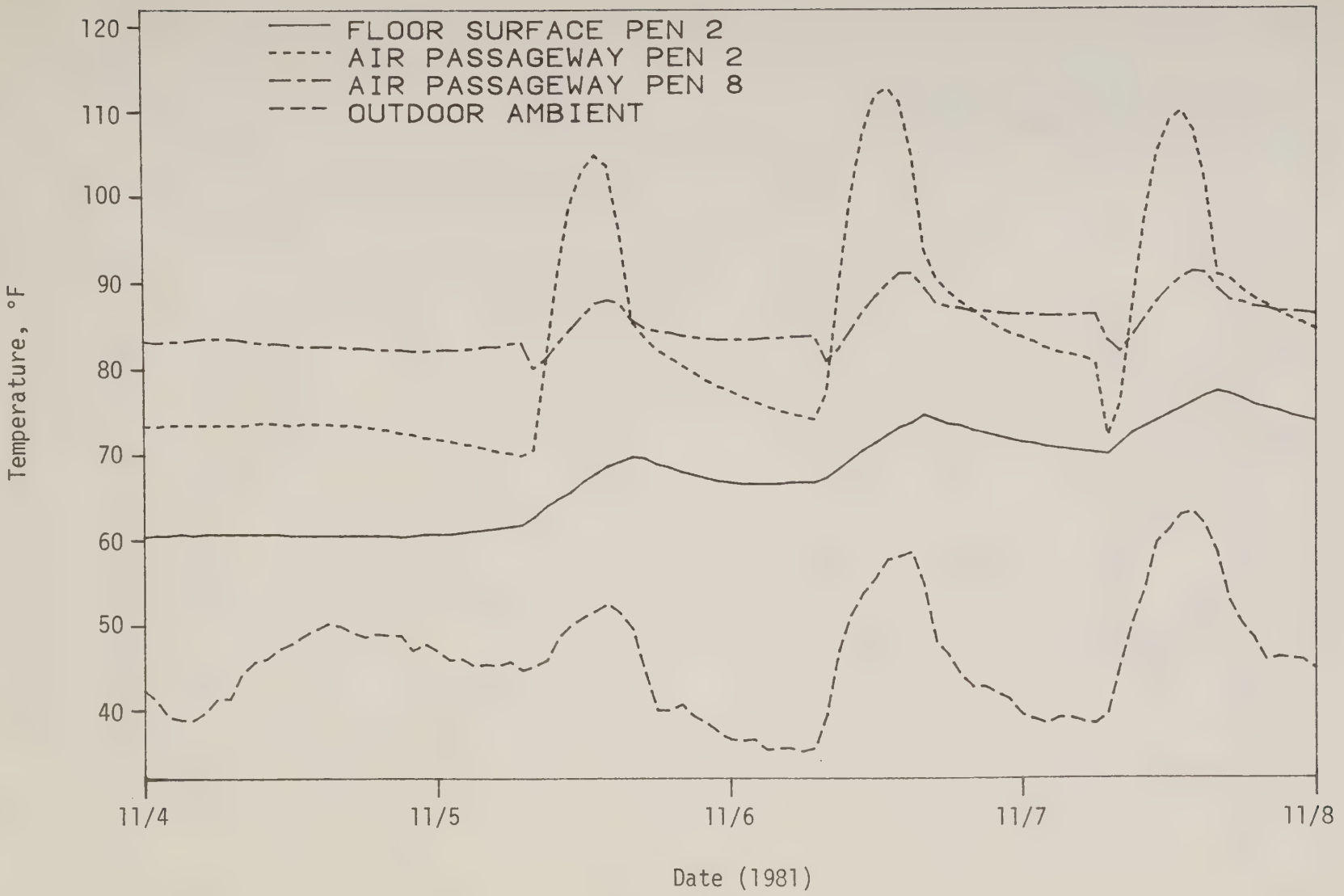


Figure 4. Temperatures relevant to the IFHDS system (Larson).

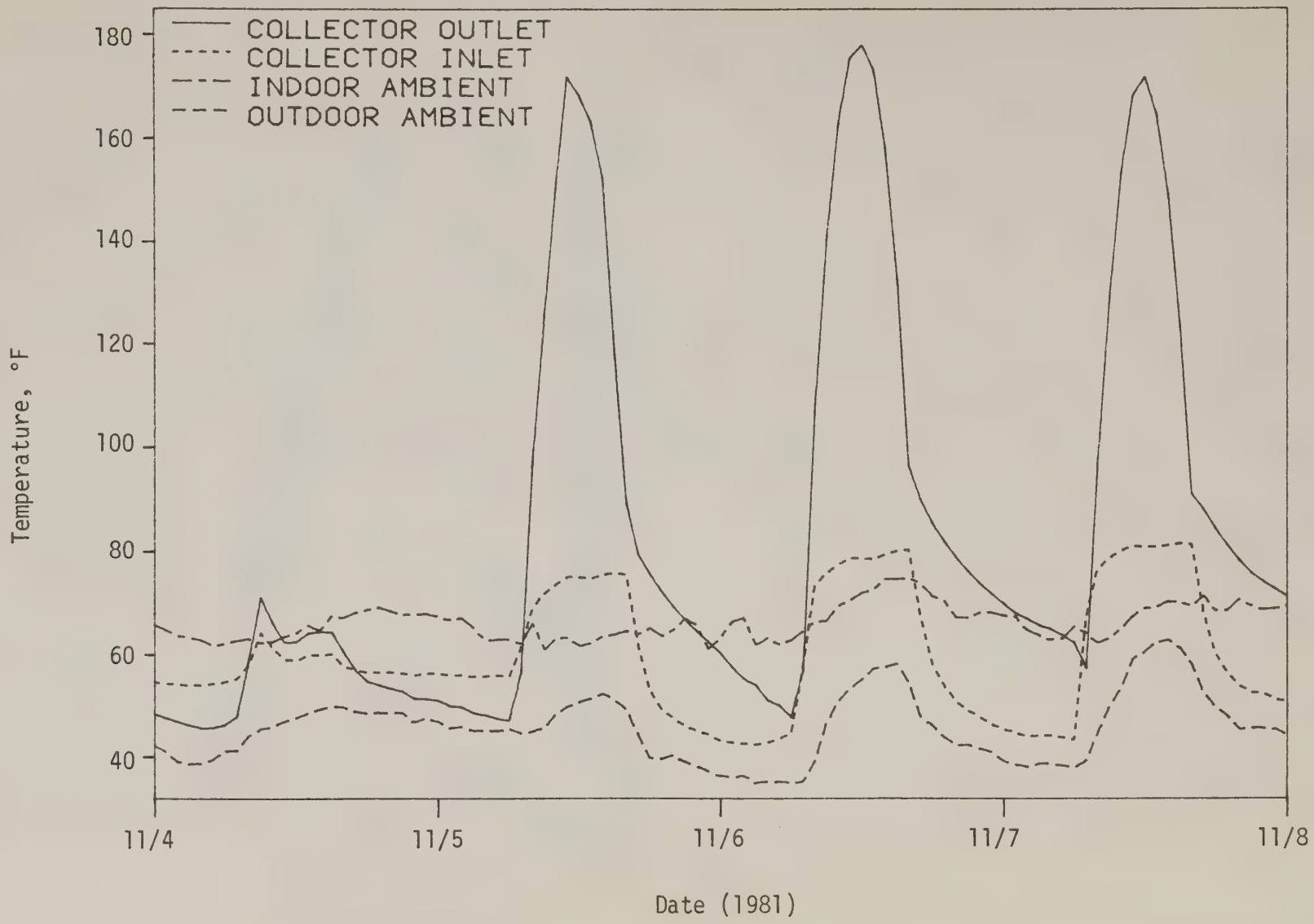


Figure 5. Temperatures relevant to the thermal performance of the Solar MOF Nursery (Larson).

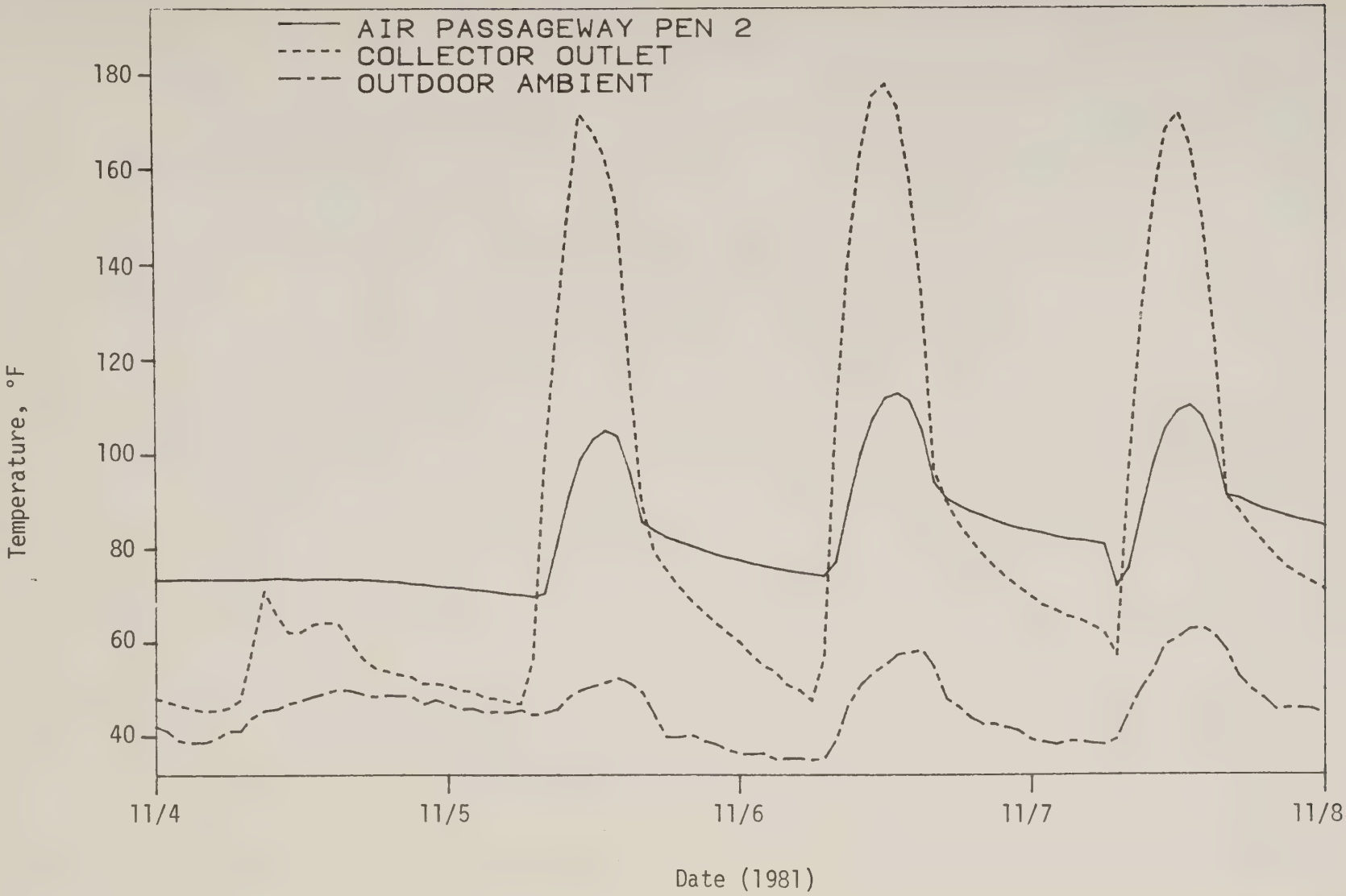
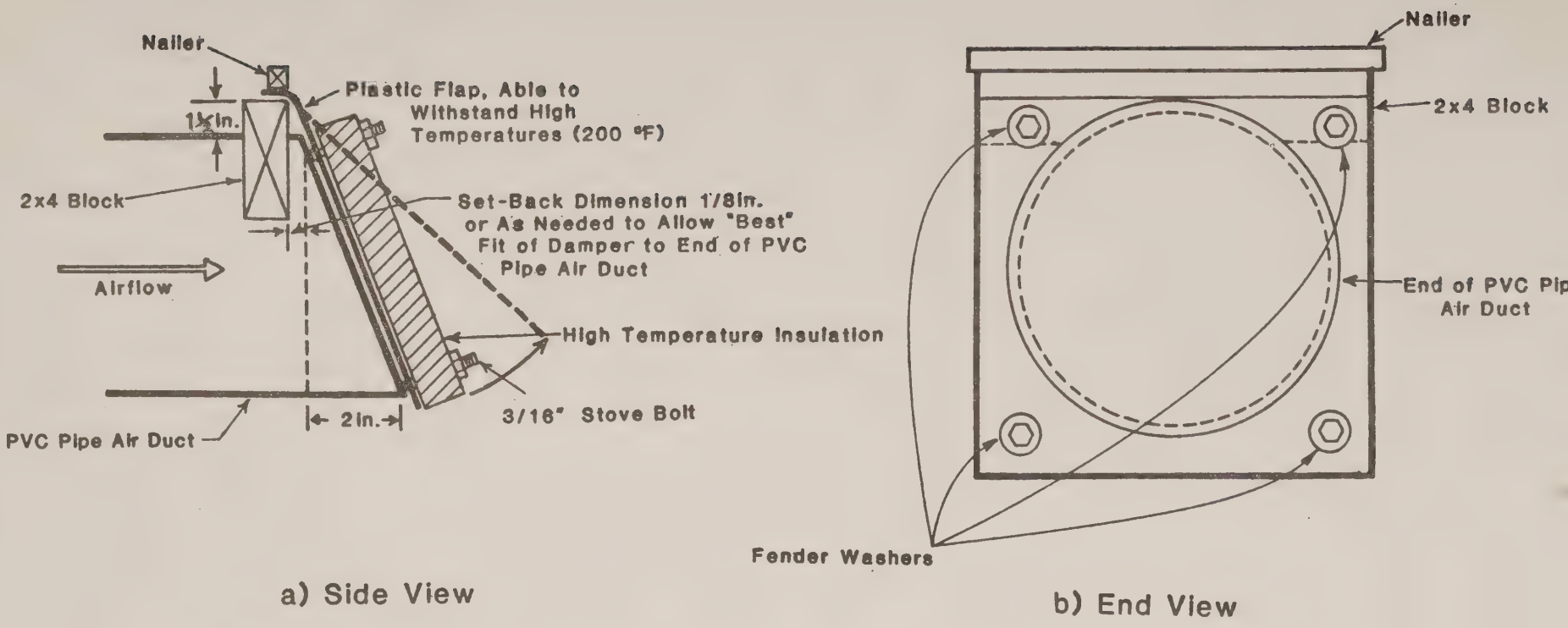
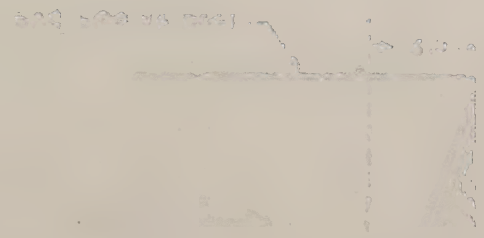


Figure 6. Temperatures at the outlet end of the air ducts (Larson).



NOTE: Use clear silicone caulk "adhesive" between the 2 x 4 block and the PVC pipe air duct to hold the block in place. Also use a bead of silicone caulk on either side of the plastic flap between the 2 x 4 block and the nailer. Place silicone caulk between the washers and the plastic flap and between the insulation and the plastic flap.

Figure 7. Back-draft dampers recommended for outlet ends of PVC pipe air ducts (Larson).



OHIO

SOLAR HEATING OF LIVESTOCK STRUCTURES

Randall Reeder
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The Ohio State University
September 1982

Summary

Five swine and two dairy farmers completed the Ohio solar demonstration project. They installed a wide range of solar systems including simple solar attics and systems with heat stored in water, rock and phase-change salt. Solar collector sizes varied from 275 to 3200 square feet with costs from 35¢ to $47 per square foot. The simple payback (system cost divided by current annual fuel savings) ranged from about four years to over a hundred. Energy conservation practices adopted by all seven farmers reduced total fuel requirements.

Project Objectives and Overview

The primary objective of this program was to demonstrate the technical and economic feasibility of using solar energy to provide significant amounts of the heat required for livestock structures in Ohio. Other key objectives included demonstrating the value of energy conservation techniques, identifying incentives and opportunities for widespread adoption of solar energy technology and to establish a base of facilities and knowledgeable personnel for a strong Extension program in solar energy and conservation.

The demonstration farms were to include swine, dairy and poultry, be distributed across the state and include a variety of solar systems.

Farmers were selected from among 30 who applied for the project. After the project director visited each farm the list was narrowed to eleven by an advisory committee. The two poultry operations were soon dropped because no suitable economical solar system design was available for the existing broiler and pullet houses. (Because of the intermittent need for heat no other poultry houses were considered as replacements.)

Two of the seven swine operations withdrew and were replaced. Another (Harlan Baldwin) asked to withdraw in early 1982 after delaying the solar installation in a new nursery building. (He still plans to install it.)

Two dairies were included in the project but one (Richard Forbes) did not finish his solar heated milking parlor until fall 1982.

Therefore this report includes seven structures: five swine and two dairy.

SOLAR HEATING OF LIVESTOCK STRUCTURES DEMONSTRATION PROJECT

Name/County	Building Type	Solar System	Cost	Cost	Construction Completed	Open House(s) Date/Attend.
Wayne Upton Meigs	Swine farrowing and nursery	Solar attic	840 sq. ft.	$1/sq.ft. Total $850	Spring 1980	3-17-81 125
Richard Steiner Wayne	Swine farrowing and nursery	Solar attic	3200 sq.ft.	35¢/sq.ft. Total $1100	Fall 1979	Prohibited by health restrictions
John Greten Coshocton	Swine farrowing	Solar attic	1300 sq.ft.	$2/sq.ft. Total $2600	Winter 1979	10-14-81 35
David Brown Wyandot	Swine farrowing	Sunduit (water system)	960 sq.ft.	$12.50/sq.ft. Total $12,000	Fall 1979	8-13-81 100
Gary Ames Highland	Swine farrowing & nursery	Sunduit (water) and solar attic	1440 sq.ft. 1200 sq.ft.	$18/sq.ft. 80¢/sq.ft. Total $27,000	Fall 1979	9-29-81 100
Ed Hummon Hancock	Swine nursery	Solar air with rock storage	1200 sq.ft.	$4.50/sq.ft. Total $5400	Summer 1981	7-9-81 25 4-7-82 35
Roger Petersen Henry	Dairy milking parlor	Solar air with salt storage	275 sq.ft.	$47/sq.ft. Total $13,000	Fall 1980	4-11-80 250 4-13-82 12 Other tours 250

Procedure

The procedure for evaluating the solar systems included daily or monthly recording of conventional fuel use by the farmers and the use of one datalogger to record detailed temperature and solar data for up to one month at each site during 1980-81 and for two weeks during the winter of 1981-82. Unfortunately the Kaye Datalogger II developed numerous problems which (combined with solar system problems) prevented the desired amount of data collection on four farms. Nonetheless the limited data from these farms was sufficient to provide a clear picture of performance.

Gas meters and/or accumulating timers were installed in each building with natural or LP Gas to provide a record of conventional fuel used.

The datalogger recorded hourly the significant temperatures in the solar system and livestock building, solar radiation and, at four sites, the minutes the solar system collected energy. Water or air flow rates, measured once for each solar system, were then used with the temperature and radiation data to calculate performance. With the detailed data collected for two weeks to two months, accumulating timers connected to a solar pump or fan, provided a reasonable measure of year 'round performance, especially on the Sunduit water systems.

Educational Efforts

The solar project generates much curiosity and interest from livestock farmers, grain farmers and even homeowners. Radio, television and print media are eager to cover a solar story. The result is that Extension programs related to the demonstration project have been very effective. Ten solar field days or open house programs at the cooperating farms (including Forbes') have attracted 1200 people. Publicity and media coverage of the events reached thousands more. Through 75 formal presentations the project director has reached about 4000 farmers, Extension faculty, farm builders, engineers and students.

Manned displays at major Ohio farm shows have provided more opportunity for one-to-one discussions with potential solar users. A slide set with a 12-minute cassette tape provides a quick look at the performance of the solar systems and energy conservation. A 4' x 10' working model of a solar attic is also used to draw people to the display where solar energy fact sheets are available.

Eleven radio tapes (3 to 5 minutes) have been distributed to Ohio stations and the project director has discussed the solar project on seven live radio interviews and one television news program. About ten educational news releases concerning the project have been distributed.

A popular four page sheet "Considering Solar" was printed in 1980 and revised in 1982. Over 10,000 copies have been handed out at meetings, field days and farm shows. At each open house a mimeographed description of the solar system performance was given to each visitor.

Information on the solar project has been featured in several national and state publications including Farm Building News, Successful Farming, The Ohio Farmer, RFD News and magazines published by Milk Marketing, Inc., and the Ohio Farm Bureau Federation. The hog farmer magazine of France, "L'eleveur De Porcs" included a five page article on the Ohio solar systems and featured one of the buildings on the cover. Individual farms have been featured in local newspaper stories on solar energy.

Four fact sheets are planned on the performance of the Ohio solar systems. Two paper proposals have been submitted to the American Society of Agricultural Engineers and another has been accepted for the Second National Dairy Housing Conference.

Energy conservation has been and will continue to be emphasized in all educational efforts. Farmers who hear or read about these solar buildings are likely to use one or more energy saving ideas regardless of whether they install a solar system.

Conclusions and Recommendations

Performance and costs varied greatly for the solar systems demonstrated. Energy conservation helped reduce fuel use for all seven farmers.

Solar attics are a low cost investment and could be incorporated into the design of most new swine farrowing and nursery buildings. In Ohio a solar attic should be an economical system for heating ventilation air, paying off in about five years. Two fans are recommended for best performance: one to exhaust air in summer, the other to move air from the attic into the building in winter. The thermostatically controlled exhaust fan can assure that maximum temperatures do not exceed 175 to 190 degrees to protect the fiberglass reinforced plastic roofing. A single speed, continuous running fan should match the minimum ventilation rate for the building to help assure that all ventilating air enters through the solar attic. A simple gravity louver can permit a higher air flow from the attic on warm days.

The Sunduit water system is a questionable investment as a floor heating system in a swine farrowing or nursery building. With a few design changes to increase performance and reduce the chance of freezing the system could become economical for some Ohio farmers. The system provides useful heat year 'round but improvements are needed to improve winter performance.

The air system with rock storage on Ed Hummon's swine nursery building is a good investment. Using the entire south roof and wall for solar collection and placing the rock storage under the floor minimizes the cost. This system could be adopted by many Ohio farmers planning a new nursery or farrowing building. For a building with manure storage in pits under part of the floor the remaining space between pits would be adequate for the rock storage.

The solar system on Roger Petersen's dairy is not economical. In fact no solar system costing $47 per square foot of collector would be a good investment on any Ohio farm.

Overall solar systems with a simple design built as part of a new structure offer the greatest potential for Ohio farms. A solar attic or other collector without storage can provide up to a third of the heat needed. Solar heat storage is necessary to save additional fuel.

OHIO

SOLAR HEATING OF LIVESTOCK STRUCTURES

Randall Reeder
Extension Agricultural Engineer
The Ohio State University
September 1982

INDEX -

SOLAR ATTIC (Swine)

Wayne Upton, Meigs County

Richard Steiner, Wayne County

John Greten, Coshocton County

SUNDUIT SOLAR SYSTEM (Swine)

Dave Brown, Wyandot County

Gary Ames, Highland County

SOLAR AIR WITH ROCK STORAGE (Swine)

Ed Hummon, Hancock County

SOLAR AIR WITH SALT STORAGE (Dairy)

Roger Petersen, Henry County

Wayne Upton -- OHIO

The Farm

Wayne Upton's farm is in Meigs County, southeastern Ohio, five miles east of Tuppers Plains in the hills overlooking the Ohio River. Wayne is a part-time farmer and the 24 x 70 foot farrowing-nursery building with a solar attic is his first major investment as a pork producer.

Wayne and his two teenage sons built the structure which has been in use since February 1980. The metal-clad frame building has R-20 insulation in the ceiling and about R-15 in the stud walls. The concrete block foundation wall has R-11 polystryene on the outside. Winter ventilation is provided by a variable speed exhaust fan in each room adjusted to the minimum recommended rate.

Goals

The following objectives governed the design and construction of this building and solar system:

- Minimize total heat requirements.
- Provide a low cost solar system for preheating ventilating air.
- Select a design suitable for construction by the farmer.

System Description

The 840 square foot solar attic covers the south half of the building. Roofing is Tedlar coated fiberglass reinforced plastic (FRP). The south attic is separated from the north attic by an insulated barrier nailed to truss members. All winter ventilation air is drawn through the attic, down into the office area where heat may be added by the furnace, then into each room. (A short plywood duct picks up the attic air near the ridge.)

When the 14 crate farrowing room and 150 pig nursery are full the minimum ventilation required is about 1000 cfm. About half of this air enters through the attic and the rest through leaks.

In summer the attic is cooled by an exhaust fan and ventilation air enters the room through sidewall openings into the ducts.

Cost

The solar attic added about $850 to the cost of the building for an average cost of about $1.00 per square foot.

Performance

The performance of a solar attic is highly dependent on the energy demands of the building. Heat loss through the walls and ceiling of this structure is 150,000 to 200,000 Btu/day for October to April. The low air flow through the solar attic (less than 1 cfm/sq. ft.) reduces the efficiency of the collector to about 15%. Whether the available solar was 300 Btu/hr about 15% was effectively added to the building according to data collected in March 1981.

In seven months (October through April) this solar attic contributes about

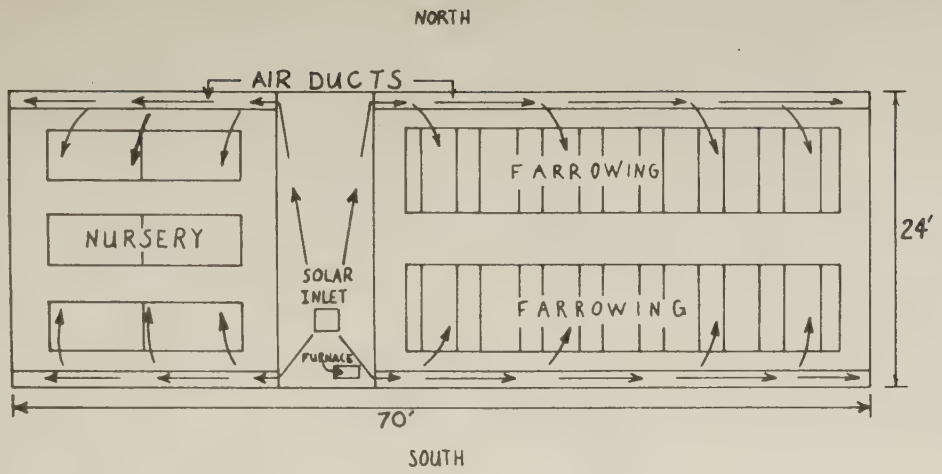
25 million Btu or 30,000 Btu per square foot of collector. If the building were used to capacity, total energy requirements would equal about 75,000,000 Btu per year (including electric heat lamps in the farrowing room). Upton's sow herd is not big enough yet to keep the building in continuous use so these conclusions are based on fuel used during short time periods. For example, for 20 days after pigs were weaned into the nursery on December 7, 1981 the building required 80 gallons of LPGas (about 300,000 Btu/day). The farrowing room was empty that month. On January 28, 1982 a new group entered the nursery and fuel use averaged about 120,000 Btu/day through February.

The seven month season totals assume a daily average of 120,000 Btu solar, 220,000 Btu LPGas and 25,000 Btu electric heat lamps. Solar provides about a third of the total replacing about $225 worth of LPGas (75¢/gal). The simple payback is therefore less than 4 years.

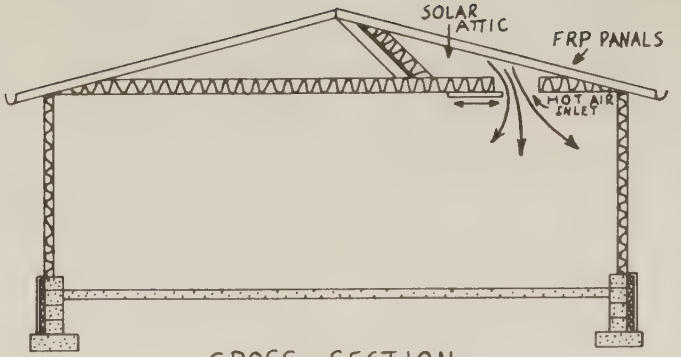
Comments

This building was constructed with considerable assistance from the Cooperative Extension Service. The building is based on an MWPS plan and Extension Agricultural Engineers designed the solar and ventilation systems.

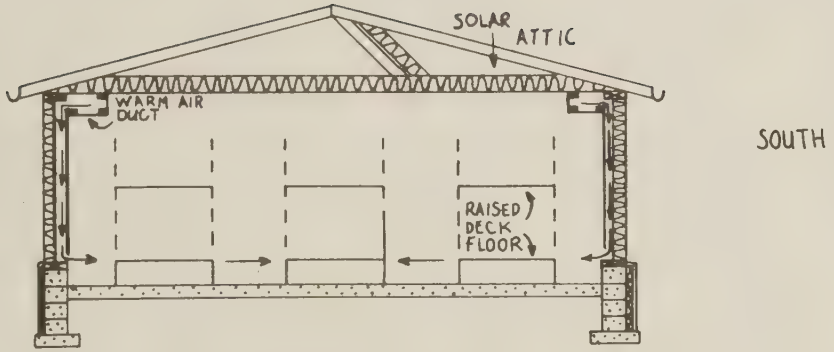
Sealing summer inlets and other leaks to force most winter ventilation air to come in through the solar attic is difficult in any livestock building. In this and other similar buildings a single speed fan exhausting from the attic into the building at a rate equal to the minimum winter room exhaust fans may be a necessary addition for best solar performance.



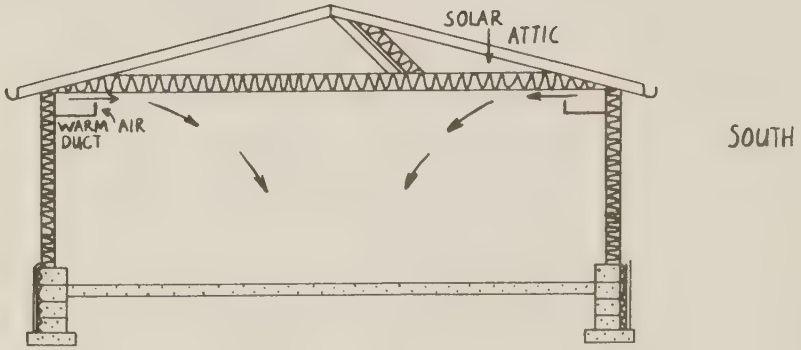
FLOOR PLAN



CROSS SECTION
SERVICE ROOM



CROSS SECTION
NURSERY



CROSS SECTION
FARROWING

WAYNE UPTON

JAN. 1981

Richard Steiner -- OHIO

The Farm

Richard Steiner's farm is in northeastern Ohio near Wooster, Wayne County, about 2 miles from the intersection of state routes 583 and 57. He produces breeding stock, marketing about 2000 hogs a year in a farrow-to-finish operation. He completed a new 40 x 80 foot farrowing-nursery building in June 1979. Because of the farmstead layout the building had to be oriented north-south. Determined to include some solar in the design, Steiner made the entire roof into an inexpensive solar attic.

The wood structure is well-insulated with 6 inches of fiberglass batts in the walls and 12 inches in the ceiling. Variable speed ventilation fans are adjusted to provide a minimum rate of about 20 cfm per sow in farrowing rooms and 2 cfm per pig in nursery rooms.

Electric heat pads are used for creep heat in the raised farrowing crates. Natural gas heaters provide supplemental heat in all four rooms maintaining a temperature of 70^{o} in the farrowing rooms and 80^{o} to 85^{o} in the nursery rooms.

Goals

The following objectives governed the design and construction of this building and solar system:

- Minimize total heat requirements.
- Provide a low cost solar system for preheating ventilating air.

System Description

The entire 3200 square foot attic is roofed with Tedlar-coated clear fiberglass reinforced plastic panels on a 3/12 slope, facing east and west. Ventilation air is drawn out of the attic at the ridge. Six 6" flexible plastic pipes convey the air to the hall along the west wall. From there it goes into each room through a louvered opening.

In summer louvers at each end of the attic are opened to permit some natural cooling. Louvers along the west wall allow outside air directly into the hall. A door near the center of the hall can be closed in warm weather to allow the farrowing rooms to be ventilated with outside air while the nursery rooms continue to draw air from the solar attic.

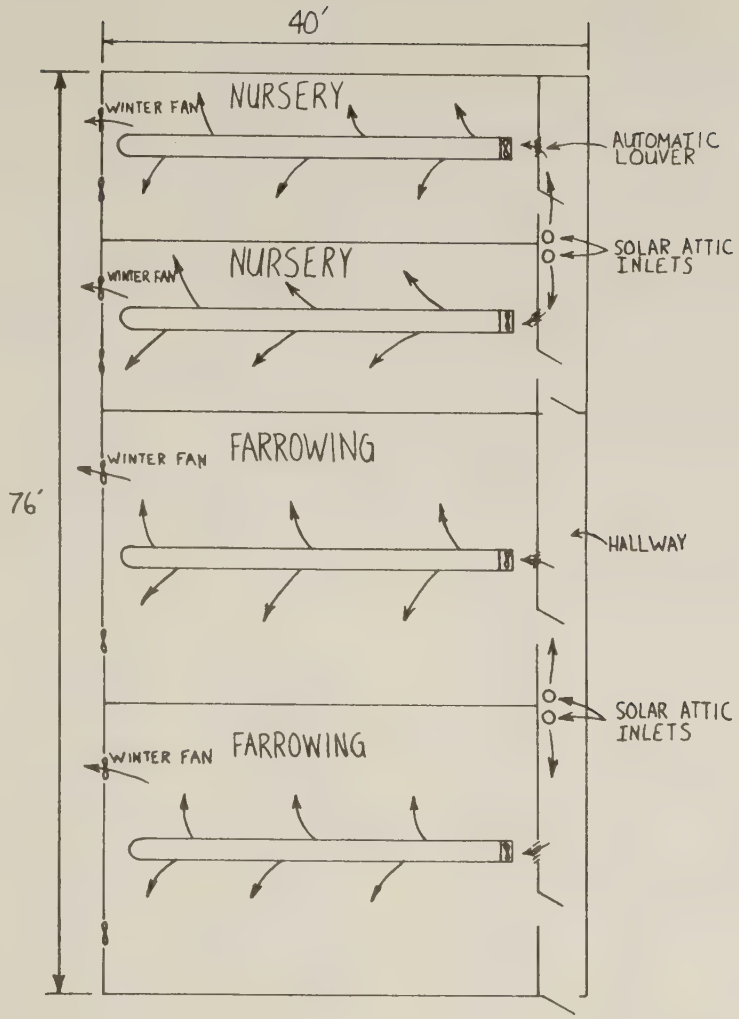
Cost

Total cost of the solar attic was about $1100 including $875 extra for the FRP roofing for an average cost of only 35¢ per square foot of collector.

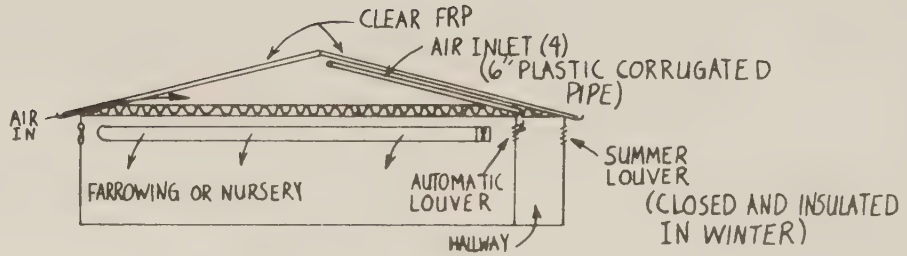
Performance

The value of this solar attic is limited by its orientation, low roof slope and the energy efficiency of the building. Yet this system, using less than 10% of the available solar, has a payback of only 4 years.

Because of the low slope roof facing east and west, snow covers the collector



FLOOR PLAN



CROSS-SECTION

RICHARD STEINER

for several days each winter. The orientation greatly reduces the collection of solar energy compared to a south facing roof. The ventilation air flow, even if it all passed through the attic, is only one-half cfm per square foot of collector. And the building is well-insulated with heat loss through the walls and ceiling of about 200,000 Btu/day from September 15 to May 15, equivalent to about 60 mcf of natural gas annually. Ventilation heat loss is replaced primarily by animal heat.

In 1981 the building used 113 mcf of gas. In the first half of 1982 it used 75 mcf. That's about 100 million Btu per year.

Solar and temperature data were recorded for three weeks in January 1981 when the roof was 75% to 90% covered with snow. Even then temperature of the attic air entering the building reached 12^{o} to 20^{o} higher than outside when solar radiation equaled 800 to 1000 Btu/ft^2/day. (Between midnight and 6 a. m. attic temperature averaged about 3^{o} above outside.)

Spot checks of daytime temperature showed a 40^{o} to 50^{o} rise was common on sunny days. Based on that information it is reasonable to assume that the solar attic provides a season average 8^{o} rise to the 750 cfm ventilating air entering through the attic. With those assumptions annual heat claimed from the solar attic is about 40 million Btu, equal to 50 mcf of gas. At $6 per mcf the yearly savings are $300 or $0.09 per square foot of collector for a 4 year payback. The 40 million Btu of solar energy represents only 5% of that available for an 8 month heating season.

Comments

A summer exhaust fan in the attic is needed to keep the peak temperature below 175^{o} to protect the FRP.

A typical metal roof may possibly provide as much useful heat year-round as this solar roof does. Only the low installation cost makes this solar attic appear reasonably economical.

John Greten -- OHIO

The Farm

John Greten operates a 300 sow swine farm in the hills of East Central Ohio near Fresno, Coshocton County. He markets about 3000 hogs a year. In December 1978 John moved 32 sows into a new 52 x 52 foot farrowing house built by a local contractor. The solar attic for preheating ventilation air is just one way John attempted to reduce fuel expenses. The walls and ceiling are insulated with 6 inches of fiberglass. One inch polystyrene foam sheets insulate under the hot water pipes embedded in the concrete floor. Variable speed fans are adjusted to provide a minimum winter ventilation rate as low as 10 cfm per sow. The primary source of heat is solid fuel boiler fired with coal from a local mine, or wood cut on the farm.

Goals

The following objectives governed the design and construction of this building and solar system:

- Minimize total heat requirements.
- Minimize cost of purchased fuel.
- Provide a low cost solar system for preheating ventilating air.

System Description

A 1300 square foot solar attic covers the south half of the building Roofing is inexpensive clear fiberglass reinforced plastic panels with no protective covering. The south attic is separated from the north attic by an insulated barrier. The barrier forms an inverted "V" under the ridge and serves as the collection duct for solar heated air in winter. Ventilation air moves down into the hall then into the farrowing rooms. In summer the solar attic is naturally ventilated by openings at the eave and ridge.

Cost

The solar attic added about $2600 to the cost of the building for an average cost of about $2.00 per square foot.

Performance

The value of this solar attic is limited by the poor quality of fiberglass roofing. The four year old FRP material is not tedlar-coated and has changed so greatly that only 20 percent of the available solar penetrates the roof. Data recorded from April 27 to May 10, 1982 indicate that the solar attic temperatures peaked at about 30^{o} above outside. On sunny days the 24-hour average rise was only 6^{o} to 8^{o}.

The low minimum ventilation of about 600 cfm (less than 1/2 cfm/sq.ft. of collector) reduces collection efficiency. Roughly seven percent of the available solar through the seven month heating season (October through April) is contributed to the building. The annual solar savings is 20 million Btu or 15,000 Btu per square foot of collector.

No records were kept of the quantity or quality or coal and wood used to heat

the farrowing house.

The solar savings, expressed as equivalent LPGas, is about 250 gallons (one-fifth gallon per square foot) worth about $185. Compared to LPGas the simple payback is about 15 years. Because the wood and coal John Greten burns has a lower cash cost than LPGas his actual payback is much longer. This solar attic is not economical.

Comments

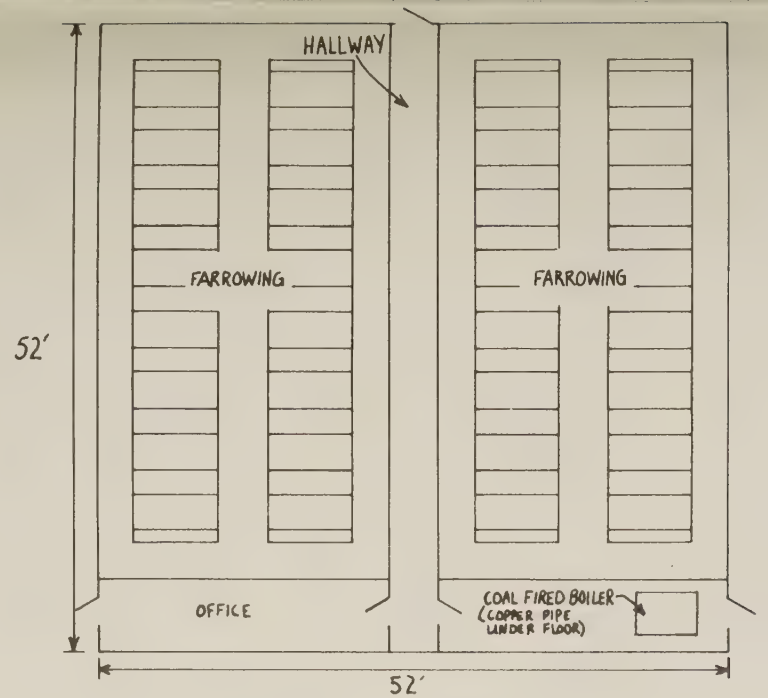
Several factors combined to make this solar system uneconomical:

- The inverted "V" ventilation inlet was an overly expensive addition that required cutting and rebuilding truss members after the roof was installed, greatly increasing labor costs.
- High quality FRP roofing would have provided about twice as much solar energy.
- Low fuel cost, ignoring extra farm labor required with coal and wood, makes the solar energy worth less by comparison.

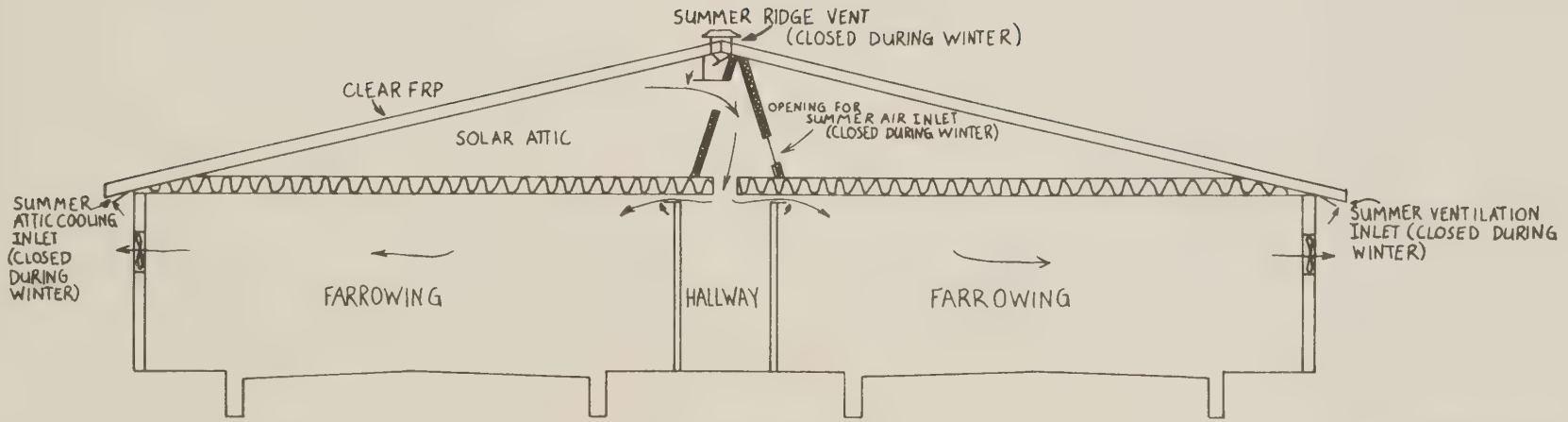
Summer ventilation air for the farrowing rooms should enter the hall from the end of the building instead of through the north attic.

This was the first solar construction by a local builder.

John Greten may replace all or part of the south roof with high quality FRP to increase the solar efficiency.



FLOOR PLAN



CROSS-SECTION

JOHN GRETEN

David Brown -- OHIO

The Farm

The "Maken Bacon" farm, owned by the David Brown family is in Wyandot County, north central Ohio, one mile from U. S. Route 23 near Nevada. The farm includes swine, grain and a beef feedlot. Sons, Tom and Randy Brown manage the farrow-to-finish swine operation which markets 3000 hogs a year.

In the summer of 1979 the Browns built a new 40-crate farrowing house to replace an old "energy obsolete" building. The new 56 x 64 foot structure is designed to save energy. The ceiling is insulated to R-20 with blown-in insulation and the frame walls total about R-15 with 5/8-inch urethane board and blown-in insulation. Urethane under the floor is R-15. Ventilation fans were selected to provide a minimum rate of about 20 cfm per sow.

The building has four rooms with a new group of ten sows scheduled to move in each week. At about 21 days age the pigs are weaned to the adjacent nursery.

Goals

The following objectives governed the design and construction of this building and solar system:

- Minimize total heat requirements.
- Install an in-floor heating system to warm the pigs.
- Select a compatible solar system to maximize year around solar savings.

System Description

The solar system by Sunduit has 960 square feet of liquid, flat-plate collectors covering the entire 45^{o} south roof.

Solar heat storage is in a 2700 gallon concrete tank. The tank, located under the floor of a service room is completely surrounded with about 6 inches of urethane. To prevent freezing the water automatically drains from the collectors into the tank anytime the solar pump is not operating.

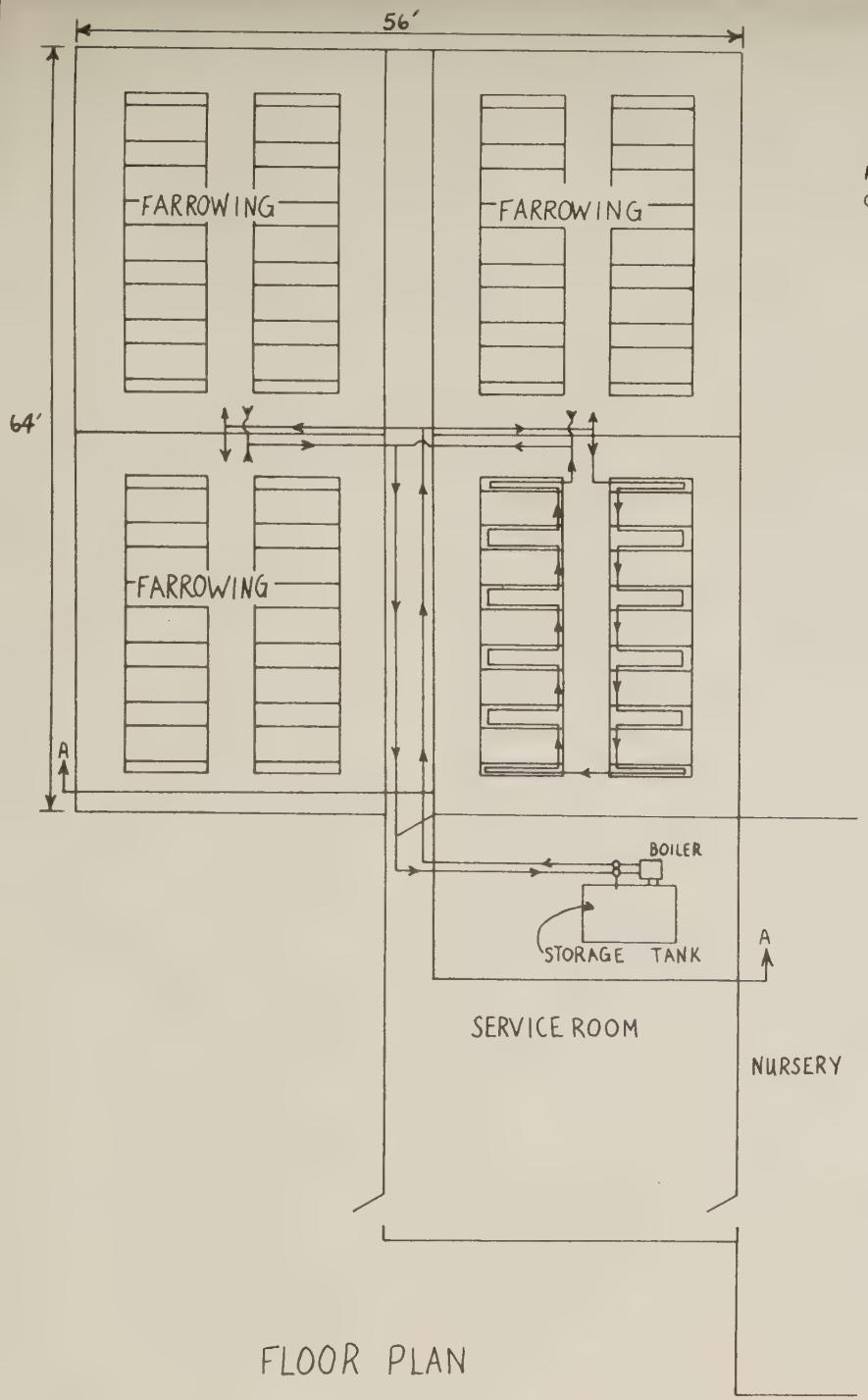
Heat is delivered to the pig creep areas by plastic pipe under the concrete floor. When the water in the storage tank drops below 105^{o} an LPGas boiler heats the water circulating through the floor.

Cost

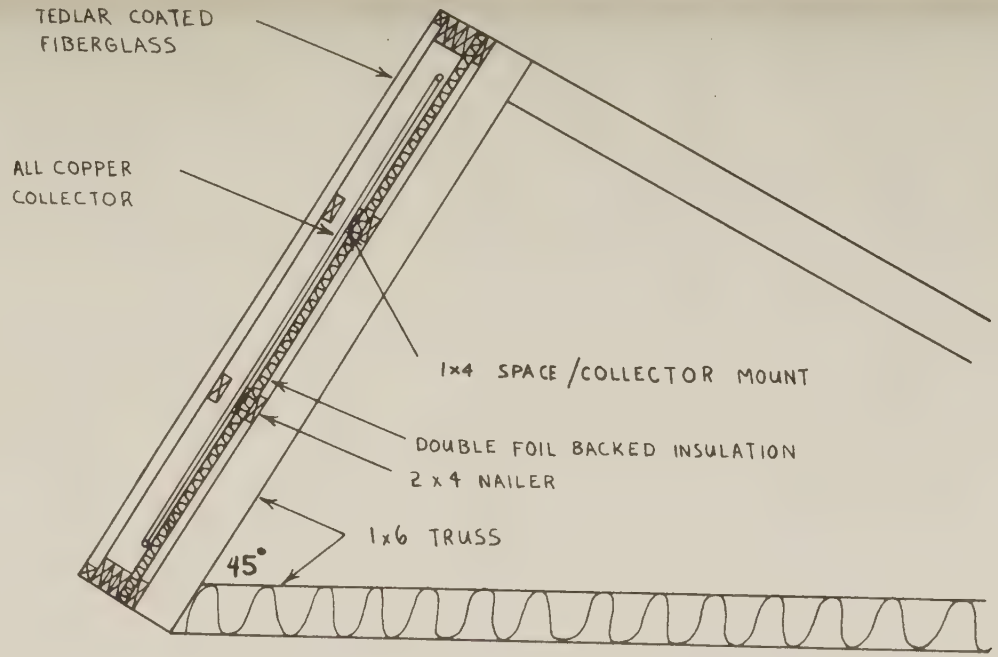
The total cost for the solar system was about $12,000 including $7000 for the materials supplied by Sunduit. The average cost per square foot of collector was $12.50.

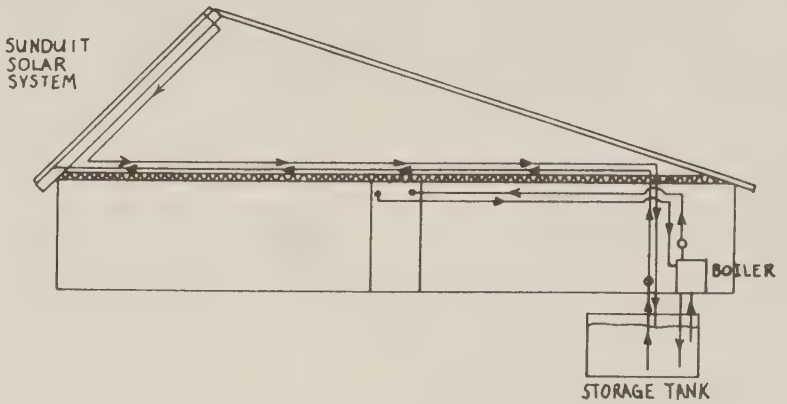
Performance

In two years starting June 1980 the building use 3200 gallons of LPGas or 1600 gal. per year. Based on data recorded since December 1980 the solar system has contributed the equivalent of about 1000 gallons of LPGas per year.



FLOOR PLAN





CROSS SECTION A-A

DAVID BROWN

In 1981 and 1982 more than 40% of the annual solar savings occurred June 1 to August 30 while LPGas consumption was less than 100 gallons each summer.

In mid-winter the boiler averages ten gallons of LPGas per day and the solar system contributes the equivalent of less than two. Electric heat lamps, used sparingly, add the equivalent of about one gallon of LPGas.

During hours of bright sunshine between 10 a. m. and 3 p. m. the solar system collects 75 to 90 Btu per square foot per hour of the available 250 to 280 Btu, giving an efficiency of 30 to 35 percent. Considering hours and days without enough solar to turn on the collector pump the year-round efficiency is about 20 percent.

Storage losses from the well-insulated tank are equivalent to about 1/4 gallon of LPGas per day so the solar system must run about 15 minutes per day to replace the loss.

The floor heating system uses warm water from the solar storage until tank temperature drops below 105^{o}. Then the LPGas boiler heats the circulating water. In winter the tank temperature usually ranges from 105^{o} to 115^{o}. After one seven day period with no collected solar the tank dropped to 96^{o}. The highest recorded summer temperature was 165^{o}.

In an attempt to improve the system performance in winter a water-to-air heat exchanger was installed in the ventilation duct. Using the solar heated water to warm cold ventilating air will allow the solar system to operate at a lower temperature range (40^{o} to 60^{o}), thus increasing the hours of solar collection and system efficiency. Results are inconclusive because of the difficulty getting all ventilating air to enter through the heat exchanger.

This Sunduit solar system is probably not economical replacing LPGas at $0.75 per gallon. The $12,000 solar system replaces about $750 worth of fuel per year for a simple payback of sixteen years.

Comments

The compact design of this solar installation helped minimize cost and improve performance. Although a sixteen year payback is not good a few modifications may improve the performance at a small additional installation cost.

Placing more pipe, closer together, in the concrete floor will allow the system to warm the building with water a few degrees cooler, thus increasing solar collection time.

In winter a water-to-air heat exchanger for heating ventilating air should provide an economical way of getting more solar heat into the building. A fan should be used to move the air through the heat exchanger and into the building. Another possibility is to move the ventilating air through the collector frame in the coldest months. (Shut off the solar water system.) Bring the air in through an opening in the back of the collector at one end and out the other end, then down through an insulated duct to the existing inlet duct. For this building an 800 cfm fan in the insulated duct would provide the minimum winter rate.

Gary Ames -- OHIO

The Farm

The Gary Ames farm is located 3 miles west of Hillsboro, Highland County, on State Route 138 in southwestern Ohio.

In 1979 Gary built a new farrowing-nursery complex as the nucleus of his swine operation which markets 4000 feeder pigs annually. The unit consists of three 24 x 70 foot buildings connected by a hall. Each building has a 12 crate farrowing room, a primary nursery with ten raised 4 foot square pens and a secondary nursery with six 8 x 11 foot pens built over a manure pit.

Ceilings have blown-in insulation (about R-21), the walls total R-10, and R-6 urethane board was placed under heated floor areas. The ventilation system in each room has a variable speed exhaust fan and automatic inlets which maintain a constant static pressure. In the second stage nursery single speed pit fans are designed to provide the minimum winter ventilation.

Goals

The following objectives governed the design and construction of this building and solar system:

- Health of the swine herd was top priority.
- Select a solar system to provide heat to all rooms.
- Reduce total heating cost.

System Design

The solar system includes both an automatic drain down water system and solar attic. The main system, by Sunduit, has 1440 square feet of liquid flat plate collectors covering about half the 45^{o} south roofs of the three buildings. Solar heat storage is in a 3000 gallon concrete tank under the floor of a service room. It is insulated with 3 inches of urethane on top and sides but none under the tank. To prevent freezing the water automatically drains from the collectors into the water tank anytime the solar pump is not operating.

Heat is delivered to the farrowing rooms through copper pipe embedded in the concrete floor. The warm water heats the floor in the pig creep area away from the sow. In the first stage nursery water circulates under the perimeter of each raised pen in iron pipe to heat the recently weaned pigs by radiation. A radiator with a fan in these three nursery rooms also helps heat the air to 80^{o}. In the secondary nursery copper pipes embedded in the 3-foot wide concrete floor slab along north and south walls provide heat. When water in the solar storage tank drops below 108^{o} an LPGas boiler heats the water circulating through the building.

Solar attics cover the nursery end of each building preheating the ventilation air for the six nursery rooms. The total solar attic collector area is about 1200 square feet. The roofing is Tedlar coated FRP. The solar attics do not have a divider panel to prevent the solar heat from escaping through the uninsulated north roof. Air from the attic is picked up at eave level (south wall in two buildings, north wall in the other) and delivered to the

nursery room through the ventilation inlets. In summer the ventilation air enters directly through the wall. Thermostatically controlled fans keep the solar attics from overheating.

Cost

The total cost for the solar system was about $27,000 including $13,000 for the Sunduit material and $10,000 for plumbing. The solar attic portion was about $1000 ($0.80 per square foot of collector). The cost of the main solar system was $26,000 for an average of about $18 per square foot of collector.

Performance

This solar system has operated at full strength only 60 percent of the time since it was completed in April 1980. The biggest problem was caused by record cold temperatures January 10, 1982. Two vacuum relief valves failed resulting in frozen pipes which knocked out two-thirds of the collector area. One-third still has not been repaired. Earlier the system was plagued with valve and pump problems.

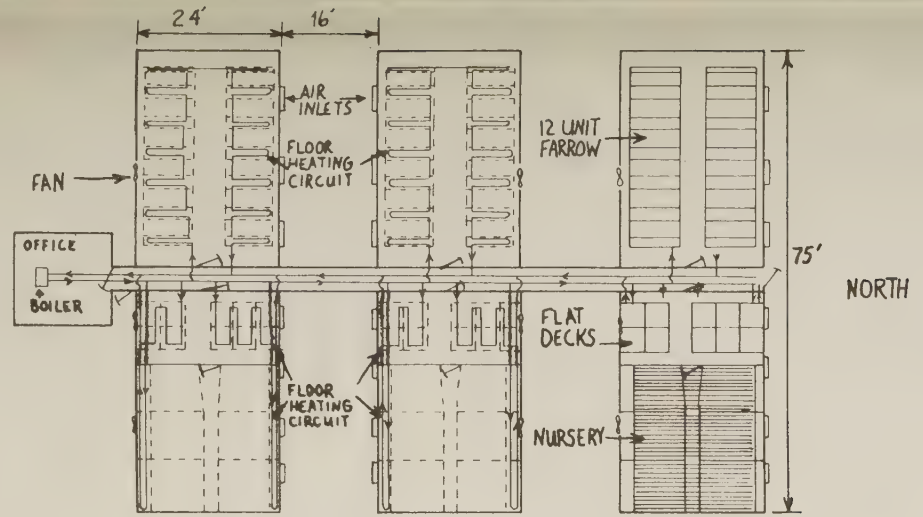
Nonetheless data recorded in February, March, May and October 1981 provides a clear picture of how the Sunduit system should work. The water system collects solar at a rate that would save the equivalent of almost one gallon of LPGas per square foot of collector per year. During hours of bright sunshine between 10 a. m. and 3 p. m. the solar system collects 75 to 90 Btu per square foot per hour of the available 250 to 280 Btu, giving an efficiency of 30 to 35 percent. Considering hours and days without enough sunshine to turn on the collector pumps the year-round efficiency is about 20 percent.

Storage losses are relatively high because no insulation was placed under the tank. The tank loses the equivalent of about one gallon of LPGas per day. The system must run more than 45 minutes a day to keep up. These storage losses cut the system efficiency to 15 percent.

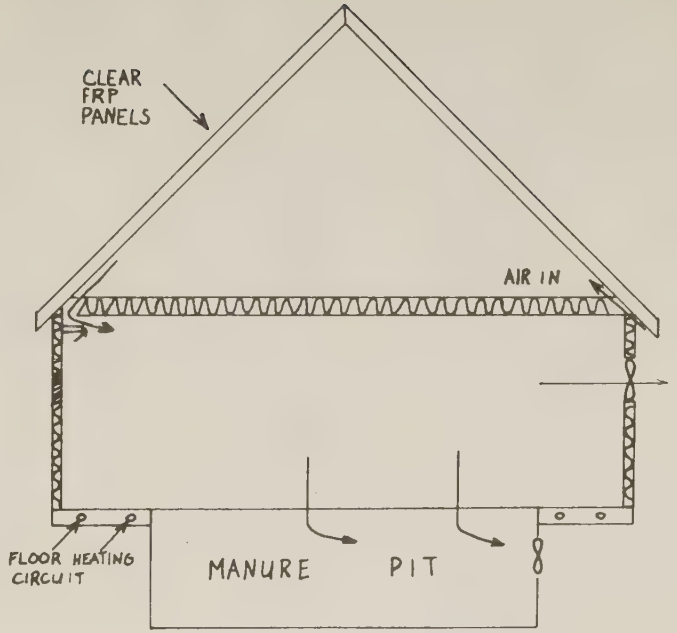
The building has used 8000 gallons of LPGas (January 1980 to September 1982) a rate of about 3000 gallons per year. The solar water system has provided the equivalent of about 600 gallons LPGas per year. If the system operates continuously at full strength it should replace over 1000 gallons per year.

The solar attics are doing very well. During hours of bright sunshine ventilating air is warmed 20^{o} to 30^{o}. Flow rate through the attics is usually 2 to 3 cfm per square foot of collector. Limited data indicates the solar attics are delivering about 20% of the available solar. If so the solar attics are providing about 50 million Btu in a seven month (October to April) heating season. The savings equal about 600 gallons of LPGas which @$0.75/gal means the payback on the solar attic portion of the system is only two years.

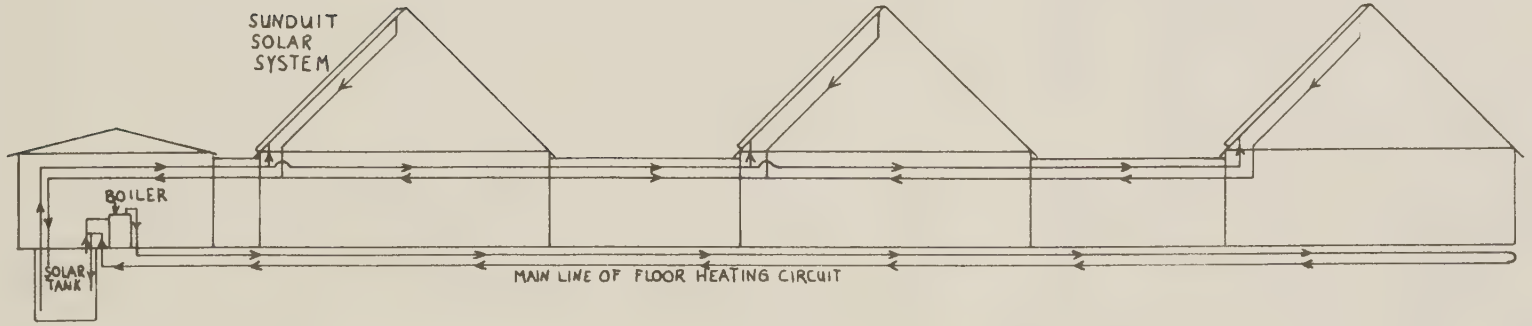
The Sunduit water system with an average savings of 600 gallons of LPGas per year has a simple payback of over 50 years. If the system were operating to



FLOOR PLAN



CROSS SECTION VIEW
SOLAR ATTIC



CROSS SECTION VIEW
SUNDUIT SOLAR SYSTEM

GARY AMES

capacity the payback would improve to about 35 years, still far from economical.

Overall the system should supply 30 to 40 percent of the buildings fuel needs.

Comments

The elaborate nature and size of this installation increased the system cost about 50 percent compared to simpler, compact layouts.

Mistakes in design and installation have resulted in about a 50 percent reduction in performance.

Extra vacuum relief valves should be installed on each collector to provide more insurance against freezing.

Ed Hummon -- OHIO

The Farm

The Ed Hummon farm, two miles west of Mt. Cory, Hancock County, in northwest Ohio markets 1300 hogs per year. In July 1981 Ed completed construction of a new solar heated nursery. The 42 x 42 foot building includes an office-service room and two 21 x 30 foot nursery rooms with a total capacity of 500 pigs.

The frame structure has 12 inches of blown-in cellulose (R-40) in the ceiling and 6 inch fiberglass batts (R-20) in the walls. Insulation for the south wall is one inch of urethane (R-8) behind the solar collector. The concrete block foundation wall has one inch of polystyrene (R-5) on the outside. Winter ventilation is provided by a variable speed exhaust fan in each room.

Goals

The following objectives governed the design and construction of this solar building:

- Minimize total heat requirements.
- Incorporate a low cost solar system into the building design.

System Description

The south wall and south roof, totaling 1200 square feet comprise the solar collector. Glazing is greenhouse grade fiberglass reinforced plastic (FRP). Closure strips and caulking seal the collector. Solar heat is stored in crushed limestone (1 to 2") under the floor of the nursery rooms. The effective storage volume is about 10 feet wide, 2 feet deep and 30 feet long under each nursery room. The entire area under the floor (42 x 30 feet) was filled with rock after it was insulated with one inch of polystyrene. The effective storage (45 cubic yards) is about half the total volume because of the air distribution pattern.

Two 700 cfm fans circulate air through the collector and storage. Air passes between the collector cover and insulated lining, up the wall, under the roof, and into a duct in the attic. The warm air enters the storage under each room in a 12 inch perforated duct, passes through about 5 feet of rock, enters a 10 inch perforated cut, and passes to a distributor duct along the south building wall.

Ventilating air passes through the storage in two 6 inch non-perforated pipes which are placed near the top of the storage in a serpentine layout. The air is drawn through the flexible plastic pipes by a fan and is distributed through a duct along the ceiling of each room. In moderate weather some outside air enters the ducts directly. On warm summer days all ventilating air enters this way. Vents at the ridge and base of the collector wall are opened in summer to cool and protect the solar collector.

Cost

The solar system added $5400 to the cost of the building for an average cost of $4.50 per square foot of collector.

Performance

Precise, long term performance information is unavailable. Data recorded April 4-12, 1982 reveals how the system performed during a cold, yet generally sunny period. Except for three days with little or no sunshine the system collected solar heat 5 to 8 hours per day, operating at 20 to 25 percent efficiency. The outdoor temperature ranged from 20^{o} to 35^{o}. The 500 cfm of ventilating air was warmed consistently to 50^{o} to 60^{o}. Temperatures in the top and middle of the rock storage varied from 60^{o} to 80^{o}. The bottom stayed at 57^{o} to 59^{o}. The temperature of the circulating solar air peaked at 120^{o} to 140^{o} each good solar day. The air dropped an average 40^{o} as it contributed about 70,000 Btu/hr to the storage. From April 1-12 the solar system collected about 4 million Btu while the building required 45 gallons of LPGas (3.5 million Btu) to maintain the nursery rooms at 75^{o} to 80^{o}.

Data was also recorded August 26 to September 10, 1981. Temperatures in the middle and top of the storage ranged from 80^{o} to 100^{o}, averaging about 25^{o} above the outside temperature. The bottom of the storage was 70^{o} - 72^{o}.

No fuel was needed in the nursery until October. One room of weanling pigs required only two gallons of LPGas from mid-December until they were removed in late January.

If the solar system operates at 20% efficiency it will provide about 75 million Btu (1000 gallons of LPGas) in a nine month heating season. Based on records of LPGas burned from December 1981 to June 1982 the nursery will require 750 to 1000 gallons annually when kept at its 500 pig capacity.

The simple payback on this solar system is about 7 years.

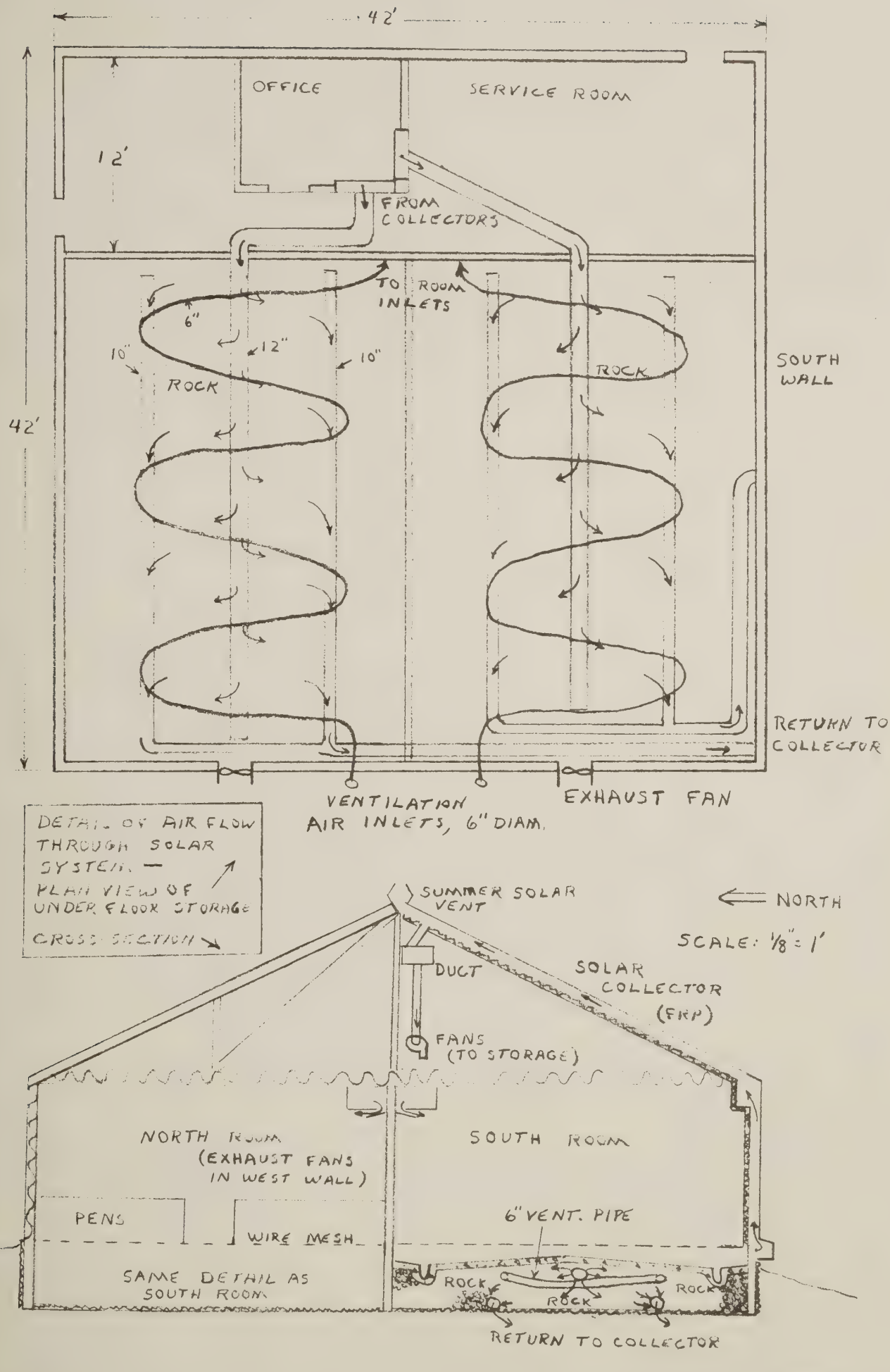
Comments

Capacity of the ventilation pipes through the solar storage is too low. A better design would have four to six parallel pipes straight through the storage. The additonal pipes would more uniformly "empty" the storage.

The summer opening on the ventilation ducts should be automatically controlled to permit more effective use of the solar system on warm spring and fall days.

In most multi-room installations the entire volume of rock under the floor should be an "active" partof the solar storage.

Ventilating air passing through the storage should enter a common duct instead of each room having its own segment of the storage.


42'
OFFICE
SERVICE ROOM
12'
FROM COLLECTORS
TO ROOM INLETS
6"
10"
12"
10"
ROCK
ROCK
SOUTH WALL
42'
RETURN TO COLLECTOR
VENTILATION AIR INLETS, 6" DIAM.
EXHAUST FAN
DETAIL OF AIR FLOW THROUGH SOLAR SYSTEM. — PLAN VIEW OF UNDER FLOOR STORAGE
CROSS SECTION
SUMMER SOLAR VENT
NORTH
SCALE: 1/8" = 1'
DUCT
SOLAR COLLECTOR (FRP)
FANS (TO STORAGE)
NORTH ROOM (EXHAUST FANS IN WEST WALL)
SOUTH ROOM
PENS
WIRE MESH
6" VENT. PIPE
SAME DETAIL AS SOUTH ROOM
ROCK
ROCK
ROCK
RETURN TO COLLECTOR

ED HUMMON

Roger Petersen -- OHIO

The Farm

Roger Petersen built a new 60-cow dairy barn in 1979 at his farm near Hamler, Henry County, in northwest Ohio.

The 1300 square foot milk house and 8 stall milking parlor are partially heated with solar energy. The building is well-insulated with 6 inches of fiberglass (R-19) in the frame walls and 12 inches (R-38) in the ceiling. Doors fit snugly to minimize air infiltration. Waste heat from the milk cooling system heats sanitation water year around and in winter helps warm the building. In winter the ventilation fan runs only about an hour after each milking to dry out the parlor.

Goals

The following objectives governed the design and construction of this building and solar system:

- Build an efficient, economical total dairy system.
- Minimize total heat requirements.
- Include a solar system to help reduce fuel costs.

System Description

The air solar systems by Solar, Inc. of Mead, Nebraska (now bankrupt) has 275 square feet of suspended plate collector with a double-pane glass cover mounted at a 60^{0} tilt on the roof of the dairy's free-stall barn. Heat is stored in 1350 pounds of phase change material, calcium chloride hexahydrate (manufactured by Dow Chemical Co.) which stores 82 Btu/lb in its melting phase change at 81^{0}. The salt is contained in 45 plastic "rods", 6 feet long and 3-1/2 inch diameter. They are stacked in a plywood box, insulated with 6 inches of polystyrene, located in the milking parlor attic about 50 feet from the collectors. Ducts between storage and collectors are one inch duct board and have a cross section area of 1-1/2 square feet. An 1100 cfm fan circulates the air.

When heat is needed in the parlor and is available in storage the furnace fan moves the return air through the solar storage and into the building. If the storage is "empty" natural gas supplies the heat.

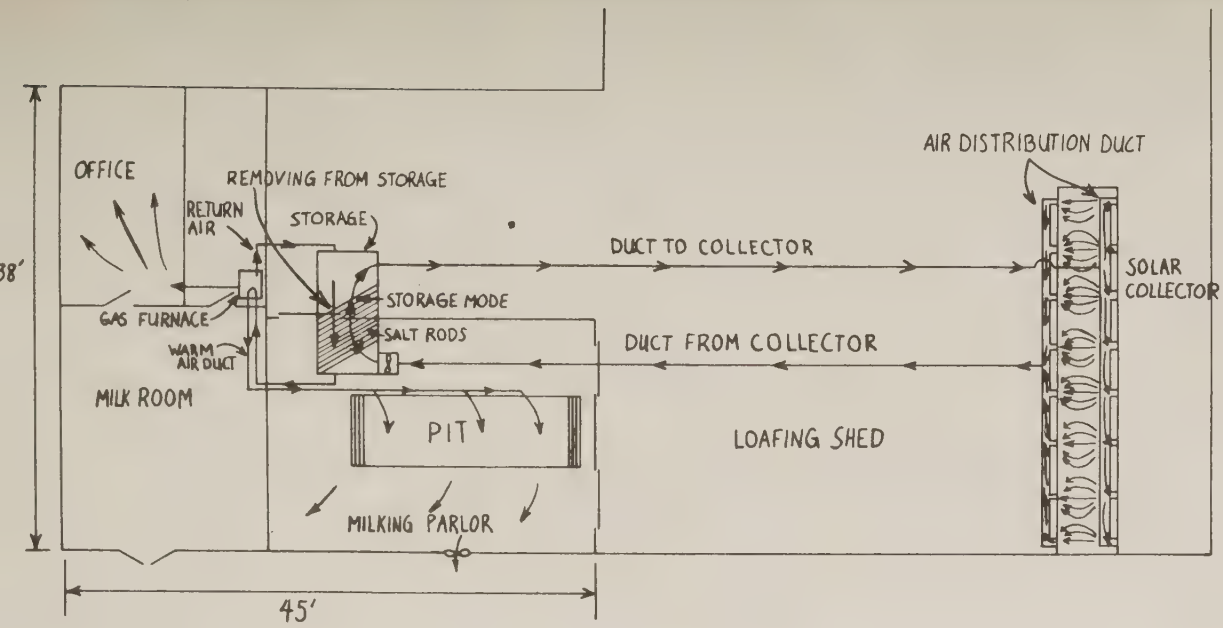
Cost

The total cost for the solar system was about $13,000 for an average cost of $47 per square foot of collector.

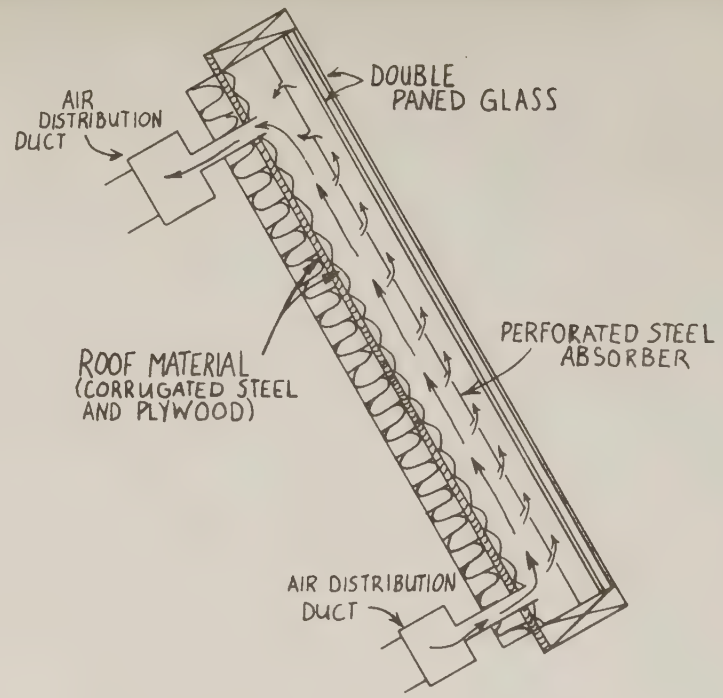
Performance

This solar system has been plagued with problems. Completion of the system was delayed a year because the supplier went bankrupt. Then problems with the controls prevented the system from operating correctly.

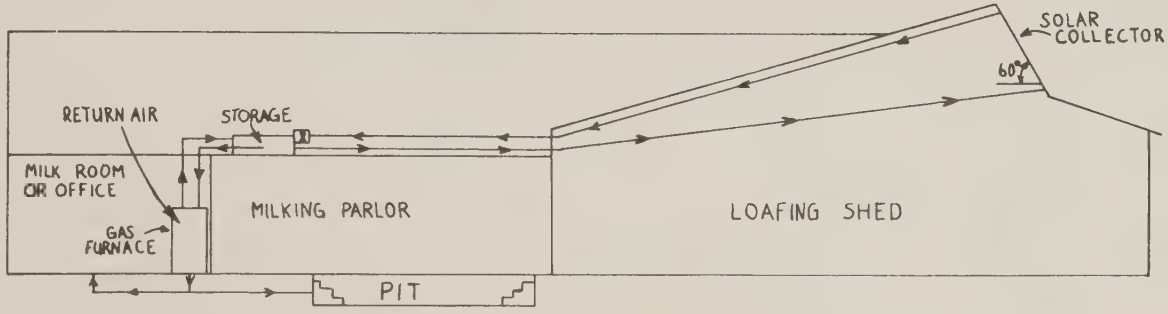
The system was monitored April 12-27, 1982 and another problem surfaced: the long ducts between collector and storage appear to be losing 50 to 75 percent



FLOOR PLAN



DETAIL OF SOLAR COLLECTOR
(BY SOLAR INC.)



CROSS - SECTION

ROGER PETERSEN

of the collected solar heat. For example, at noon on April 18, 150° air leaving the collector dropped to 123° at the entrance to the storage. The same air left the storage at 115°. Return air temperature at the collector was not recorded. The ducts, 1-inch pressed fiberglass ductboard, are well taped to minimize infiltration. Calculations show that conduction through the duct material accounts for only a small fraction of the heat losses.

If the system were operating at capacity it could save about 20 million Btu annually, replacing about $100 worth of natural gas. To achieve that level of performance the solar storage would have to be "empty" and be "refilled" every day over a six month heating season. Due to cloudy weather the heat storage would likely be filled only half of these days. Regardless, the simple payback on this system is well over 100 years.

Comments

The short heating season and the low energy requirements for a well insulated milking parlor (60 million Btu for this one) place severe limits on the price a dairy farmer can afford for a solar system. A low cost, compact design might be economical.

FINAL REPORT

SOLAR HEATING OF ON-FARM LIVESTOCK SHELTERS

- VERMONT -

Sept. 1982

by

Grant D. Wells,

Project Leader

University of Vermont

Extension Service

Burlington, Vermont

Final Report

Sept. 1982

Solar Heating of On-Farm Livestock Shelters -- Vermont

This is a summary and final report of Vermont's part to the USDA/DOE project entitled, "Solar Heating of On-Farm Livestock Shelters". An individual summary of each project site is included in the appendix of this report.

The contents of this report are:

- Overall project summary
- Project accomplishments in relation to the original objectives
- Monitoring summary
- Economic evaluation
- Conclusions: Solar potential in Northeastern livestock agriculture
- Appendices:
  - Summary: Brief description of each project
  - Table I: General project information
  - Table II: Summary of information dissemination
  - Table III: Summary of solar systems and construction information
  - Table IV: Economic payback
  - Complete illustrated summary of each project

OVERALL PROJECT SUMMARY

The University of Vermont Extension Service submitted a proposal for the use of solar energy for heat on livesotck and poultry farms in February 1979. From approximately 50 farms visited in 6 counties, 8 were selected as prospective sites for demonstration projects.

The selection was based, in part, on such factors as location, accessibility, farms reflecting typical Vermont agriculture, management level, and apparent willingness of farmer to cooperate. Substitutions were later made for 4 of the 8 because further analysis indicated solar would not be effective as a demonstration at the site, or economic pressures forced the farmer to abandon the project, or because of delays by the cooperator in getting the project started. The 4 substitutions did not much alter the types and variety of solar systems in the overall program, but the geographic distribution was narrowed from 6 to 4 counties in the state.

The first solar system was completed in August of 1979 and the last in the Fall of 1981. All solar systems were monitored at least one year or heating season. The average complete monitored time was 1½ years or heating seasons per project. Partial monitoring has continued for longer periods.

All solar systems continue to be operational for the purpose planned with every indication that the cooperators intend to continue using them. Table I is a summary of general information for each project site.

All 8 cooperating farmers have been excellent in their cooperation, and positive spokespersons for solar. For example, Mr. Simpson, owner of the first project completed (project D) has unselfishly travelled many miles to speak at meetings, arranged by Extension, Grange, Farm Bureau, etc., about solar and his experiences with his solar calf barn.

All systems, once operational, have functioned as planned with only minor problems now and then. The one possible exception is project B where the performance has been below standard. Other problems are discussed in appropriate summaries contained in the appendix.

A total of $21,860 of the program's money was used to share the costs of the 8 projects at an average rate of 60% of the actual cost of the solar system if it had been constructed without cost share monies.

PROJECT ACCOMPLISHMENTS IN RELATION TO ORIGINAL OBJECTIVES

This section summarizes the project accomplishments in light of the original objectives and plan of work as set forth in the project proposal submitted in February 1979.

The first objective was to design and have constructed prototype systems on 8 farms. This was accomplished as part of the first phase of the project and in the manner outlined in the original proposal. All plans were reviewed by USDA/DOE officials before being implemented.

The second objective was to monitor and evaluate. This was accomplished in second phase, just now being completed, in a manner pretty much as outlined in the proposal. Quarterly reports were submitted to USDA as required in phase II. Further statements on monitoring are contained in the next section.

The third objective involves information dissemination. Table II summarizes what has been accomplished so far. The following items remain to be done and are being worked on at present.

1. A 20 minute video tape summary of the project using prerecorded interviews with the cooperators. This will be for the general public and, in the main, be a testimonial for solar in agriculture.

2. A 10-12 minute slide/tape cassette audio/visual program for use by Extension agents and others. This will contain material slightly more technical and specific than the video presentation.

3. A 20-25 page publication utilizing the information similar to that presented in the appendix of this report, only printed and bound in Extension bulletin format.

4. Two, 15 minute TV programs, one scheduled for November and the second, utilizing the video tape of item 1 above, in February or March of next year.

When these 4 items have been completed, we will have finished all steps of the program of work outlined in the original proposal except for the 5-day, in-depth workshop. Based on attendance at meetings dealing only

with solar in agriculture held in this state, and the overall lack of specific solar applications in Northeastern agriculture, it is felt that it would be a waste of time and resources to try to produce a workshop at this time.

MONITORING SUMMARY

Briefly, the monitoring of liquid based solar systems required daily involvement on the part of the cooperator. Water meters and temperature sensors were installed, the latter to indicate solar water temperature. The cooperator recorded temperature and water use just prior to using the water for whatever purpose. Source water temperature was measured and recorded approximately once a month. This information was sufficient to make fairly accurate estimates of solar energy utilized.

Air based systems required continuous monitoring systems in order to record temperatures, and where possible, air flow rates. Usually, air flow was assumed constant over a period of time based on singular evaluations. The end use values arrived at are probably more in question than those for liquid based operations. In two cases, estimates were based on heat balance calculations for the building and solar system in question.

Solar radiation was measured for periodic periods of time at 5 different sites. It was these measurements on which solar to heat conversion efficiencies were based (see table III). Watt-hour meters were used to measure electrical energy inputs.

Total investment in instrumentation exceeded $30,000.

COST EFFECTIVENESS

Table IV summarizes the effectiveness of the solar systems in terms of energy units and dollars per square foot of collector.

Over the past 3 years, energy costs have escalated at a rate of about 9 to 10 percent in Vermont. This does not equal the cost of capital (interest rates). Therefore, the simple payback analysis as figured in the Table IV is considered conservative. Also, many projects had recorded no maintenance costs during the period monitored. However, there are signs that many will require significant maintenance costs within a few years.

The average payback for the 8 projects is over 25 years. Naturally, the best payback is shown when the cost of energy being replaced is the highest. Projects D and F are similar except in the value of energy being replaced. Winter electricity costs about twice that of LP gas. The payback for the project replacing electricity (project F) is 11 years, and the project replacing LP gas (project D), 20 years. Question: If cooperator F had not built a "solar" calf barn, would he have selected electricity or LP gas to heat his barn? More than likely he would have considered the cheaper fuel source. Therefore, is the real payback on solar for this project 11 years as calculated or 19 years as it would be if the cheaper fuel source is used as a reference?

From the payback figures shown in Table IV, the general conclusion is that in most cases, solar systems in Northeastern livestock agriculture are not viable unless subsidized, based on the initial costs, to the extent of

50 percent or more. Because of the unfavorable payback in terms of years, it is not mentioned in the individual project summaries contained in the appendix. Rather, the initial costs are given as well as quantities of energy contributed by solar. The reader can place a price on that energy and make his own conclusions as to whether or not solar is worthwhile.

CONCLUSIONS: Solar Potential in Northeastern Livestock Agriculture

As a result of this project, this writer is forced to conclude that solar appears to have limited potential in Northeastern livestock agriculture. The primary livestock/poultry agricultural enterprises in Vermont do not need much heat in relation to other energy needs for efficient and effective production. When heat is required, the need is often so concentrated in time and space (young stock and chick brooders, for example) that present solar systems cannot supply this heat on a direct economic competitive basis.

If solar is to have a significant impact on Vermont agriculture, we have to look first at dairy production. (90% of the state's agricultural income is derived from dairy.) Solar can supply heat for 3 possible needs on a dairy farm: space heat for milk rooms or centers, heat for water used in those centers, and space heat for calf nurseries. But, with a closer look at operation and management options, we find many low cost alternatives to solar. For example, heat exchangers in milk rooms to heat water are 4 times more cost effective than solar. For this reason, no solar demonstrations were even considered for this purpose in Vermont except project B, the dairy goat project, where the ratio of milk heat available was considered insufficient for the amount of water heat needed.

Further, healthy calves can be raised in cold environments without supplemental heat. This leaves only the case of space heat for milk rooms. Even here, solar is hard pressed to show favorable economic returns because the heating season is foreshortened by the low set temperatures.

Considering a typical 100 cow Vermont dairy farm with a well insulated milking center, we find that out of a total operating budget of approximately $170,000 less than $200 is required for heat, or approximately .1 of 1 percent of the total operating budget. This is hardly significant enough for the dairyman to even take the time to consider it, realizing that he has to have the backup heating unit installed in any case.

Solar heating has potential for selected, specialized production systems in the Northeast, such as veal calf and poultry operations as illustrated by cooperators E and G of this project. Even here, with present energy costs, farmers will need subsidies before they can safely invest their money in solar.

APPENDICES

Summary (brief descriptions) of all projects

Summary of: Project A (Boivin)

Project B (Hooper)

Project C (Foster)

Project D (Simpson)

Project E (Visser)

Project F (McReynolds)

Project G (Devoid)

Project H (Small Meadows)

SUMMARY (Brief Descriptions)
SOLAR DEMONSTRATION PROJECTS
VERMONT

SOLAR FARM PROGRAM

Project A — NO-MON-NE Farm Associates; Boivin, owners

Addison Town, Addison County
Dairy farm: 90 milking cows, 400 acres
New (1981) 40x56 ft. milking center with solar sunspace
Solar system: a 57 ft. sunspace (greenhouse) along southern wall for space heating of milking center.
Cost: $8,479 in 1981
Performance: 15-18 million Btu's, saves purchase of 150-200 gallons of fuel oil annually, equivalent to 60% of milking center space heat.

Project B — Barnyard Chorus Farm; Hooper, owners

Brookfield Town, Orange County
Dairy goat farm: 50 milking goats, 60 acres; pasteurizes, bottles, and retails goat milk.
New (1980) 24x24 goat milking center including milking parlor, milk processing room, and solar hot water heating system.
Solar system: Active draindown solar hot water heater to supplement needs for sanitation and pasteurization. Wood stove and electricity used for backup.
Cost: $3,583 in 1980.
Performance: 7 million Btu's, saves 2,000 kw-hr annually, equivalent to 40% of milking center hot water needs.

Project C — Foster Brothers Farms, Inc.: Foster, owners

Middlebury, Addison County
Dairy farm: 400 milking head
Solar system: passive retrofit design for a 16x30 ft. milking center converted to a calf nursery. System utilizes south facing metal roof and concrete block wall as collectors. Ventilation air is drawn through roof collector (430 sq.ft.). No heat storage here. Mass of block wall (300 sq.ft.) is used for thermal storage. Solar energy is reradiated into nursery during afternoons and evenings of good solar days.
Cost: $3,358 in 1980.
Performance: 6 million Btu's, equivalent to about 60 gallons of fuel oil saved annually, about 20% of total space heat needs for this calf nursery.

Project D — Don-Sim Farm: Simpson, owners

Sutton, Caledonia County
Dairy farm: 200 registered Holstein animals
New (1979) 24x50 ft. calf barn with solar collector

Issued in furtherance of Cooperative Extension work, Acts of May 9 and June 30, 1914, in cooperation with the United States Department o
Agriculture, William A. Shimel, Director of Extension Service, University of Vermont, Burlington, Vermont. The Extension Service, Universit

Project D (cont.)
Solar system: 200 sq.ft. of single pass solar collector (trombe wall) designed to preheat ventilation air before entering calf barn.
Cost: $2,040 in 1979.
Performance: 8 million Btu's, about 100 gallons of LP gas saved annually, equivalent to 90% of the space heat required to maintain this barn at 46 deg. F. and 80% rH or less.

Project E

Raymond Visser Farm: Visser, owners

Addison Town, Addison County
Dairy veal calf grower, 236 pens, approximately 700 veal annually.
Solar system: 300 sq.ft. of site built collector, rack mounted against south end of barn; 500 gallons of non-pressurized water storage. Hot water is used to prepare calf feed.
Cost: $7,559 in 1980.
Performance: 36 million Btu's, or about 360 gallons of fuel oil saved by solar annually, about 34% of water heating requirements for this cooperator.

Project F

Everett and Martha McReynolds: McReynolds, owners

Danville Town, Caledonia County
Dairy farm: approximately 75 milk cows (Jerseys), 150 total head and 250 acres.
New (1981) 24x40 ft. calf barn with solar collector.
Solar system: 300 sq.ft. of single pass solar collector (trombe wall) designed to preheat ventilation air before entering calf barn.
Cost: $2,799 in 1981.
Performance: 12 million Btu's equivalent to about 3,500 kw-hr of electricity saved by solar annually.

Project G

Maple Meadows Farm: Devoid, owners

Salisbury, Addison County
Poultry: 26,000 layers; cleans, grades and retails eggs
Solar system: active water heating system, 140 sq.ft. site built collector, roof mounted, 240 gallons pressurized water storage. Hot water used in egg washing operation (40,000 cases annually).
Cost: $5,591 in 1980.
Performance: 16 million Btu's or about 160 gallons of fuel oil saved by the solar system annually. This is about 27% of the water heating needs for this operation.

Project H

Small Meadows Farm: Earthbridge Community Land Trust, owners

Putney, Windham County
Small, general farm; mixed livestock
Solar system: greenhouse attached to barn (200 sq.ft.); breadbox water heater in one corner of greenhouse (30 gallons); thermosiphoning mass wall to heat milk room (55 sq.ft.).
Cost: $2,883 in 1980.
Performance: 9 million Btu's annually (estimated).

Table I: General project information.

Project I.D.	Cooperator Name	Location (County)	Farm Business	Indicator of Farm Size	Type of Solar System	Solar Heat Used For:	Year Installed
A	Boivin	Addison	dairy	90 milking	air; attached greenhouse	space heat; milking center	1981
B	Hooper	Orange	dairy goat	50 milking	water; draindown	clean-up; milking center	1980
C	Foster	Addison	dairy	350 milking	1. air; roof collectors 2. air; thermal mass wall	pre-heat ventilation; calf nursery space heat; calf nursery	1980
D	Simpson	Caledonia	dairy	100 milking	air; single pass trombe wall	space heat; calf barn	1979
E	Visser	Addison	dairy veal	236 ties	water; closed loop	feed; dairy veal	1980
F	McReynolds	Caledonia	dairy	75 milking	air; single pass trombe wall	space heat; calf barn	1981
G	Devoid	Addison	poultry	26,000 layers	water; closed loop	clean eggs; egg room	1980
H	Small Meadows	Windham	mixed livestock	5 animal units	1. air; attached greenhouse 2. air; thermal-siphoning wall 3. water; breadbox	space heat; barn space heat; milk room clean-up; milk room	1980

Table II: Summary of information dissemination.

1. TV -- "Across the Fence" - 17 minute regularly scheduled Extension Service program broadcast 5 days a week at 12:10 p.m. on the largest commercial station in Vermont. Estimated viewing audience: 100,000 in U.S. and Canada.

   8 programs finished; 2 more planned

   Letter response to each program: approximately 50 for a total of 400

   Other TV includes 3, 5 minute segments on morning news of another local station and 1, 2 minute interview on evening news.

2. Radio - 21, 3 minute radio tapes distributed to 27 Vermont and neighboring state stations

3. Press and news releases: There have been a large number of news items and press releases carried in local, regional and national newspapers and magazines. It is impossible to make an estimate of the number and the size of audience.

   Selected items include a major news item in the Boston Globe of 24 August 80; a one page article in "Farm Buildings News", July 1980, a national magazine for the farm building industry; and an article entitled "Vt. farms - fertile ground for solar" which appeared in the March 1981 issue of NESEC Update published by the then Northeast Solar Energy Center.

4. Official site visits and tours for invited guests as advertised and open to the public:

   14 official visits and open houses: approximate attendance - 800

   Note: each site has been visited with a group of 10 or more people at least once.

5. Meetings devoted to solar energy or alternative energy where solar was part of the program:

   10 (7 in Vermont, 2 in New York, 1 in Massachusetts):

   -- approximate total attendance -- 800

6. Information sheets: 9, each up-dated 3 times

   -- approximate distribution -- 3,000

7. Mailing list: 200 names, approximately 500 mailings

8. Exhibits: 3 scale models and 1 information display have been used at county fairs, energy fairs, libraries, schools and other locations almost continuously throughout the state, especially during the summers of 1980, 81, and 82.

9. Professional papers: 3 papers have been given based on this project, 2 at northeastern regional meetings and one at a national meeting of the American Society of Agricultural Engineers.

Table III Summary of solar systems and construction information.

Project I.D.	Gross Collector Size, sq.ft.	Heat Storage	Collector Construction	Source of Labor Used for Construction	Heating Seasons Monitored	(1)	(2)	Operation Problems
A	650	Yes; 60 lbs. concrete per sq.ft. of collector, and water storage	site built	contracted and farm	1 winter	17	60	slow in finishing project
B	66	Yes; 100 gallons water	factory built	contracted	1½ years	11	20	controls
C	1. 430	No	retrofit site built	farm	2 winters	5	20	--
	2. 300	Yes; 3-core masonry block wall, 45 lbs. per sq.ft. of collector				10		
D	200	Yes; 185 lbs. concrete per sq.ft. of collector	site built	contracted and farm	2 winters	35	90	--
E	300	Yes; 500 gallons water	site built	contracted	2 years	28	34	leaks (minor at present)
F	300	Yes; 140 lbs. concrete per sq.ft. of collector	site built	farm	1½ winters	35	80	--
G	140	Yes; 240 gallons water	site built	contracted	1½ years	22	27	unable to maintain pressure
H	1. 200	Yes; 100 gallons water	site built	farm	1 winter	--	75	--
	2. 55	Yes; 70 lbs. concrete per sq.ft. of collector	" "	"	"	--		
	3. 12	Yes; 30 gallons water	" "	"	"		25	

(1) Estimated efficiencies of solar conversion to useful heat, %.

(2) Total heat required for production supplied by solar, %.

Table IV: Economic payback.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A	0.027	oil	12.50	13.05	--	39	75/25
B	0.03	elec.(summer)	11.70	54.29	0.12	**	50/50
C	0.0076	oil	13.90	4.60	--	43	60/40
D	0.04	LP gas	12.18	10.20	--	21	75/25
E	0.121	oil	12.10	25.20	0.17	20	50/50
F	0.04	elec.(winter)	20.51	9.33	--	11	55/45
G	0.118	oil	12.50	37.28	0.12	27	50/50
H	0.03	electricity	14.60	10.80	--	26	60/40

(1) Project Identification.

(2) Annual useful energy supplied by solar system to production system, MBtu/sq.ft.

(3) Energy source being supplemented by solar.

(4) Cost of replaced energy, $/M(end use)Btu's.

(5) Installed cost of solar system, $/sq.ft.
(Note: some of these figures differ from previous reports because of re-evaluation of costs directly attributed to solar.)

(6) Annual operational and maintenance costs, $/sq.ft.
(Note: Based on actual costs reported. This is probably low if considering life cycle costs.)

(7) Simple payback on total cost of system, years.
(column 5 divided by the difference of column 2 x column 4 - column 6)

(8) Approximate cost share, project/farmer.

** This system has had some operational problems.
Estimated payback with proper operation is 50 years.

SUMMARY

SOLAR DEMONSTRATION PROJECT A

NO-MON-NE Farm Associates

Addison, Vermont

Cooperator: Paul and Mark Boivin

Location: Jersey Road, 3.3 miles south of Panton, VT

Farm business: Dairy; approximately 90 milking head; cultivating 400 acres; crops: corn, alfalfa

Description of milking center: 40x56 ft. new construction (1981); milking parlor with double 6 herringbone, automatic take-off; hospital and treatment area, office, bath, utilities, milk room with bulk-headed milk tank, and solar sunspace. See figure A-1.

Insulation: walls: 6" fiberglass, approximate R = 20
ceiling: 12" fiberglass, approximate R = 36
windows: double pane, approximate R = 2
perimeter: 2" polystyrene, approximate R = 8

Ventilation: natural

Supplemental heat: passive solar and forced hot air downdraft multi-fuel furnace

SOLAR SYSTEM: 10x56 ft. (floor) passive sunspace (or greenhouse) on south side of milking center. Approximately 600 square feet acrylic double-wall sheet glazing tilted 45 degrees above the horizontal. Concrete in floor and backwall, and water in 55 gallon containers used for thermal storage. Fans circulate air from sunspace into milking parlor and utility room when heat is needed. Air is drawn from the milking pit area through ducts under the cow platform into the sunspace as shown in figure A-2.

Summer cooling: The summer cooling effect has not been documented. However, the cooperator feels that this is an important side benefit of the system. In the summer, the sunspace acts as a heat chimney, as shown in figure A-3, drawing air through the building from the north side, air that may be a few degrees cooler, thus keeping the milking parlor comfortable, even on hot days.

Installed cost of solar system: $8,480 (approximately $13 per square foot of glazing).

Performance: This solar system has supplied 15-18 million Btu's, or the equivalent of 150-200 gallons of fuel oil per heating season. This solar system has reduced the heating costs to this milking center by 60 percent.

Solar consultant to this project: Douglas Taff, Parallax, Inc., Hinesburg, VT.

Problems and suggestions for improved design:

The major change suggested for this project is that the tilt of the glazing should be 60-70 degrees for this latitude, instead of 45 degrees as installed. In fact, it is estimated that costs of construction in a vertical position (90 deg.) would be sufficiently lower to offset any slight decrease in collector efficiency at this position compared to 60 degrees. Also, it would be easier and less costly to install movable insulation panels behind vertical glazing, thus offering a low cost potential of reducing overnight heat losses. Vertical glazing would be recommended in future construction.

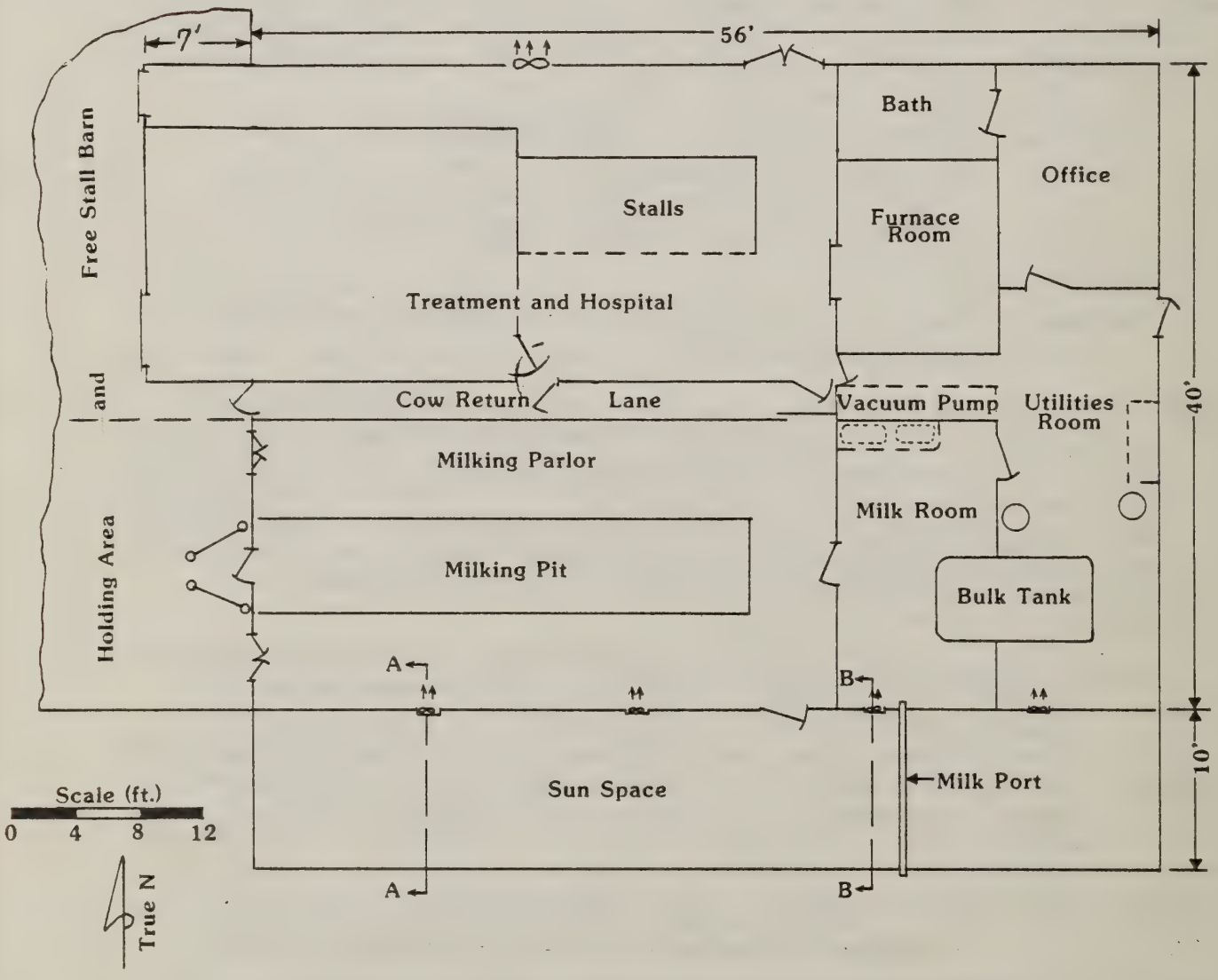


Figure A-1: Floor plan of Boivin milking center.

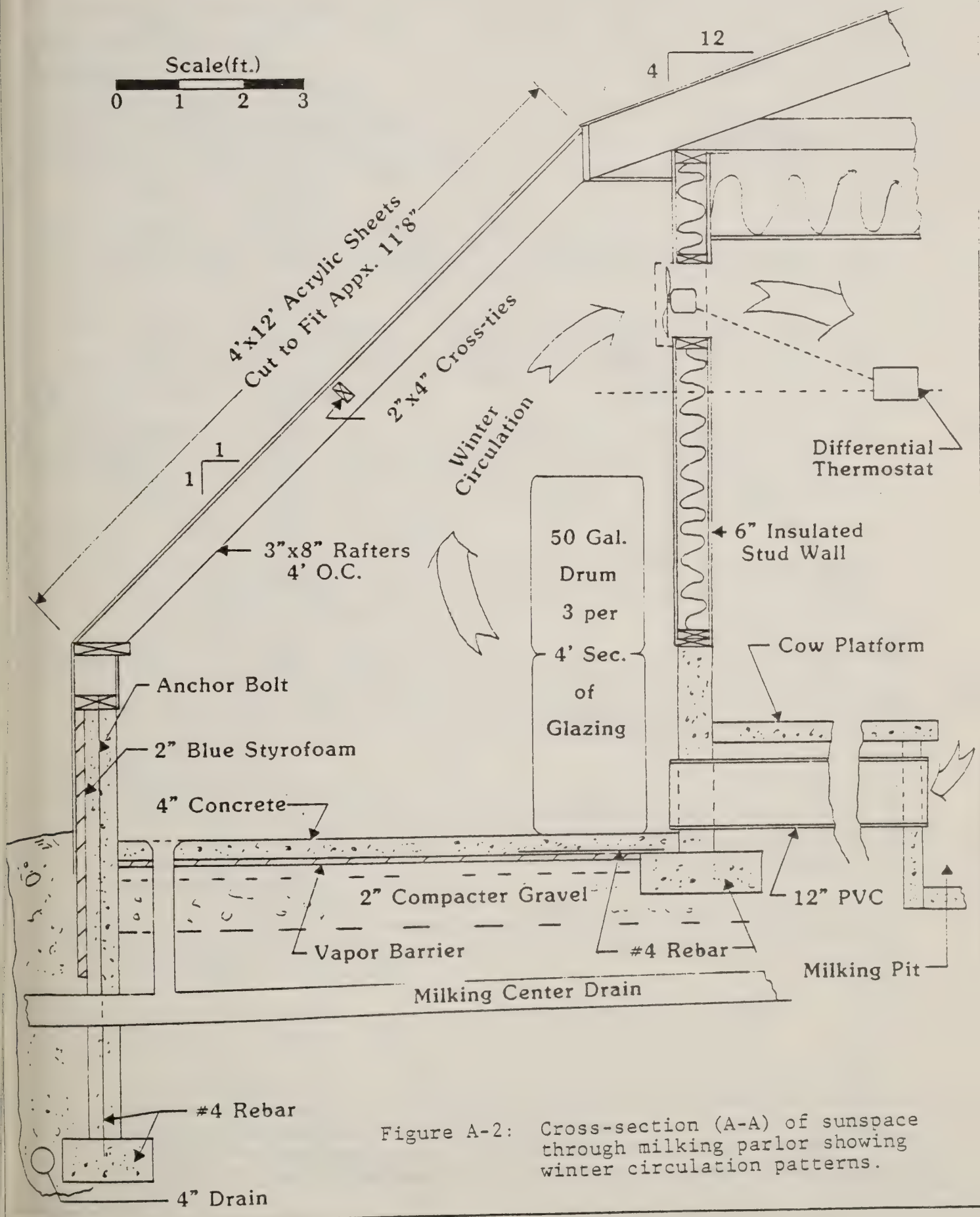


Figure A-2: Cross-section (A-A) of sunspace through milking parlor showing winter circulation patterns.

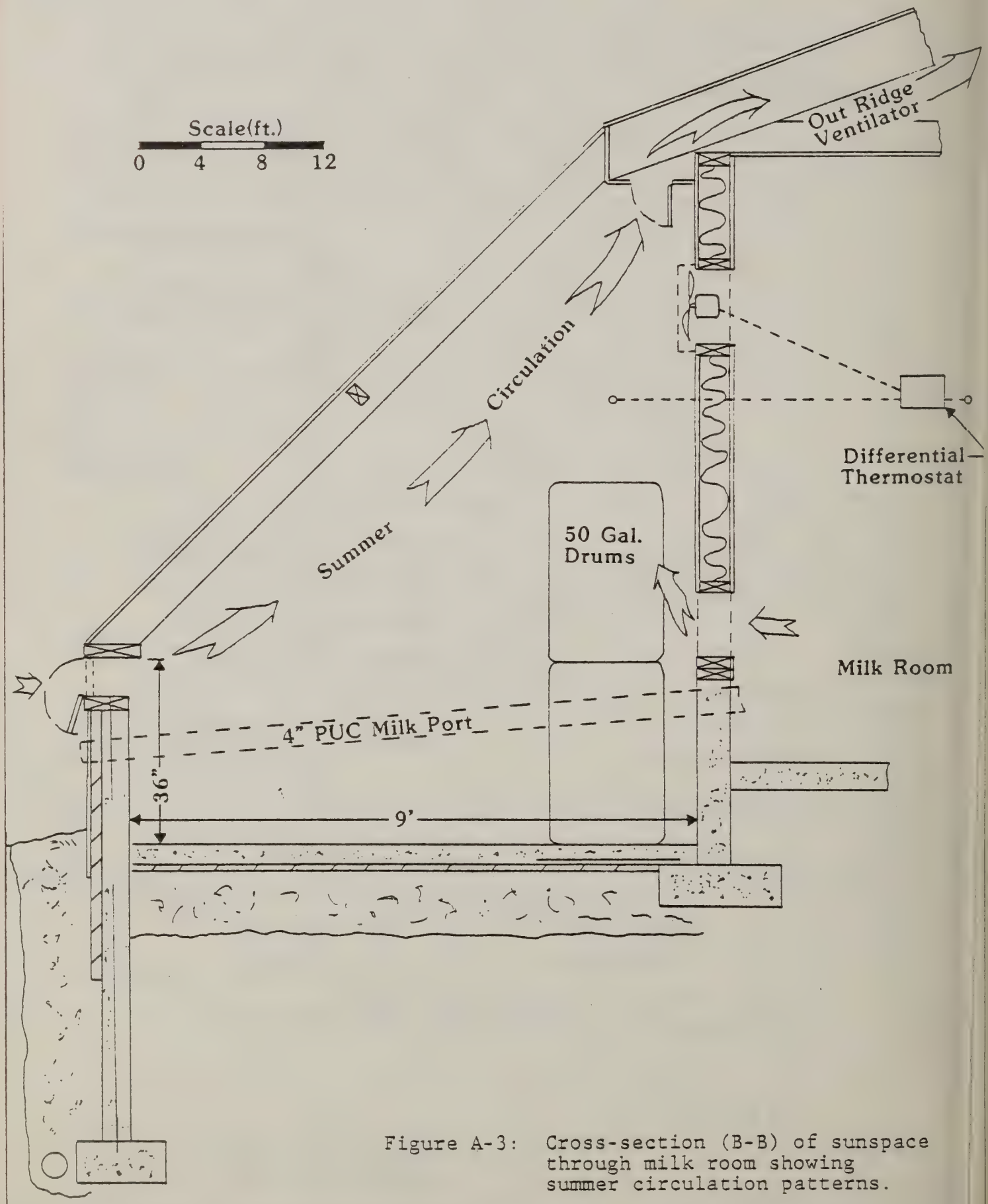


Figure A-3: Cross-section (B-B) of sunspace through milk room showing summer circulation patterns.

SUMMARY

SOLAR DEMONSTRATION PROJECT B

Barnyard Chorus Farm

Brookfield, Vermont

Cooperator: Alice and Don Hooper

Location: Approximately .4 miles east and .7 miles north of East Brookfield village.

Farm business: Dairy goat; milking approximately 50 goats; pasteurizes, bottles and retails approximately 18,000 gallons annually; cultivates approximately 60 acres; crops raised: hay.

Description of milking center: 24x24 ft. structure, 2x4" stud frame construction, newly completed spring 1980. Layout: milking parlor with 4 platform ties, milk storage and processing room, and utilities as shown in figure B-1.

SOLAR SYSTEM: 66 square feet of active hot water solar collector. Water is utilized for clean-up and sanitation of milk utensils. 3-4x6 factory built collectors, water circulation, drain down heat transfer system, 100 gallon water storage. Figure B-2 shows a cross-section of the solar collectors.

Back-up heat: Wood stove for space heating with coil to supply hot water heat in winter (solar is shut down during winter), and a 15 gallon tank with electric heating coil.

Other energy conservation devices: Heat exchanger in 100 gallon storage tank makes it possible to recycle heat from milk to water and back again during the pasteurization and cooling processes. See figure B-3 for plumbing schematic of solar and energy conservation system.

Cost: Materials for the solar system cost $2,082. The installed cost was $3,583. This included all labor and materials for the rack, panels, circulation system, controls and storage tank. It is estimated that the annual maintenance and operation costs of this system will be about $25 annually.

Performance: It is estimated that this solar system will supply about 7 million Btu's annually when it is working properly. This is equivalent to about 2,000 kw-hr.

Energy consultant to this project: Dodd Stacy, Project Engineer, Creare, Inc., Hanover, NH.

Problems and suggestions for improved design: This design has not performed as expected. A draindown system is not recommended for the severe cold climates of Vermont. One collector has burst a line once because of freezing water. It has been repaired. A closed loop system with anti-freeze heat transfer solution is recommended for this operation.

Solar systems for agricultural production should be automatic. This system is manually adjusted to operate in one mode during the solar day and another during chore time. Several different individuals are involved with chores. With this combination it is easy to see how the system is often left in an improper operation mode.

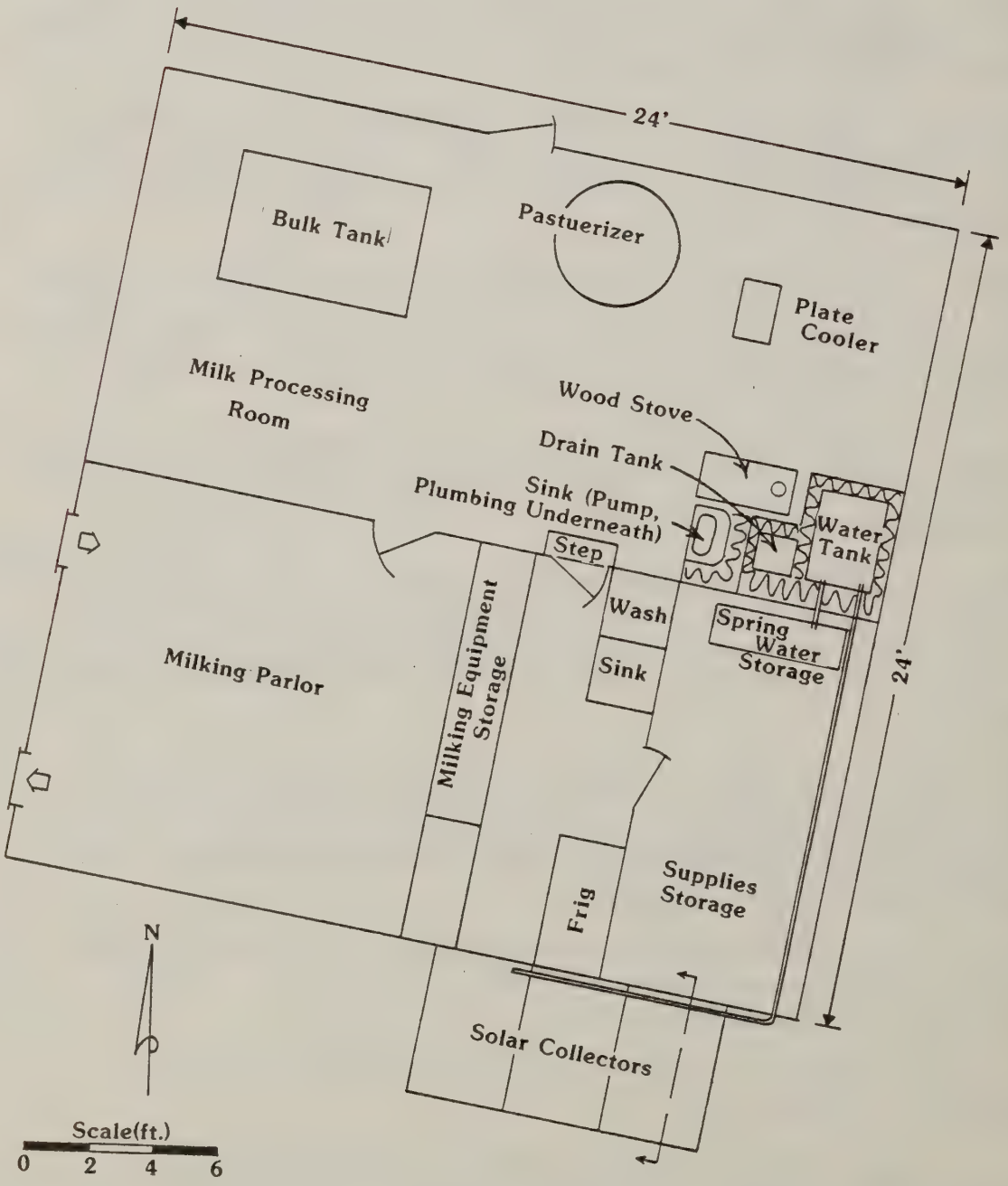


Figure B-1: Floor plan of Hooper's dairy goat milking center.

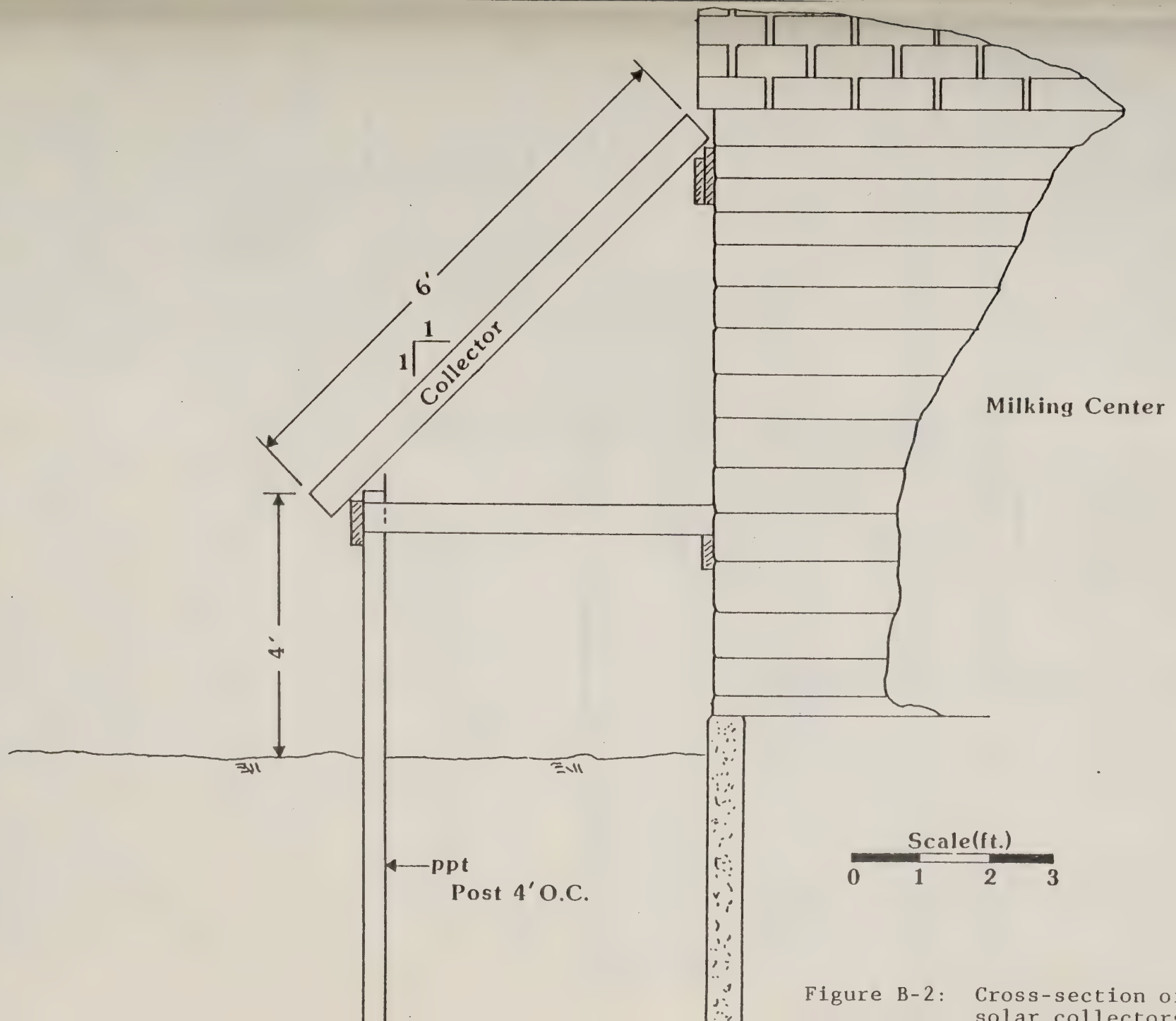


Figure B-2: Cross-section of solar collectors

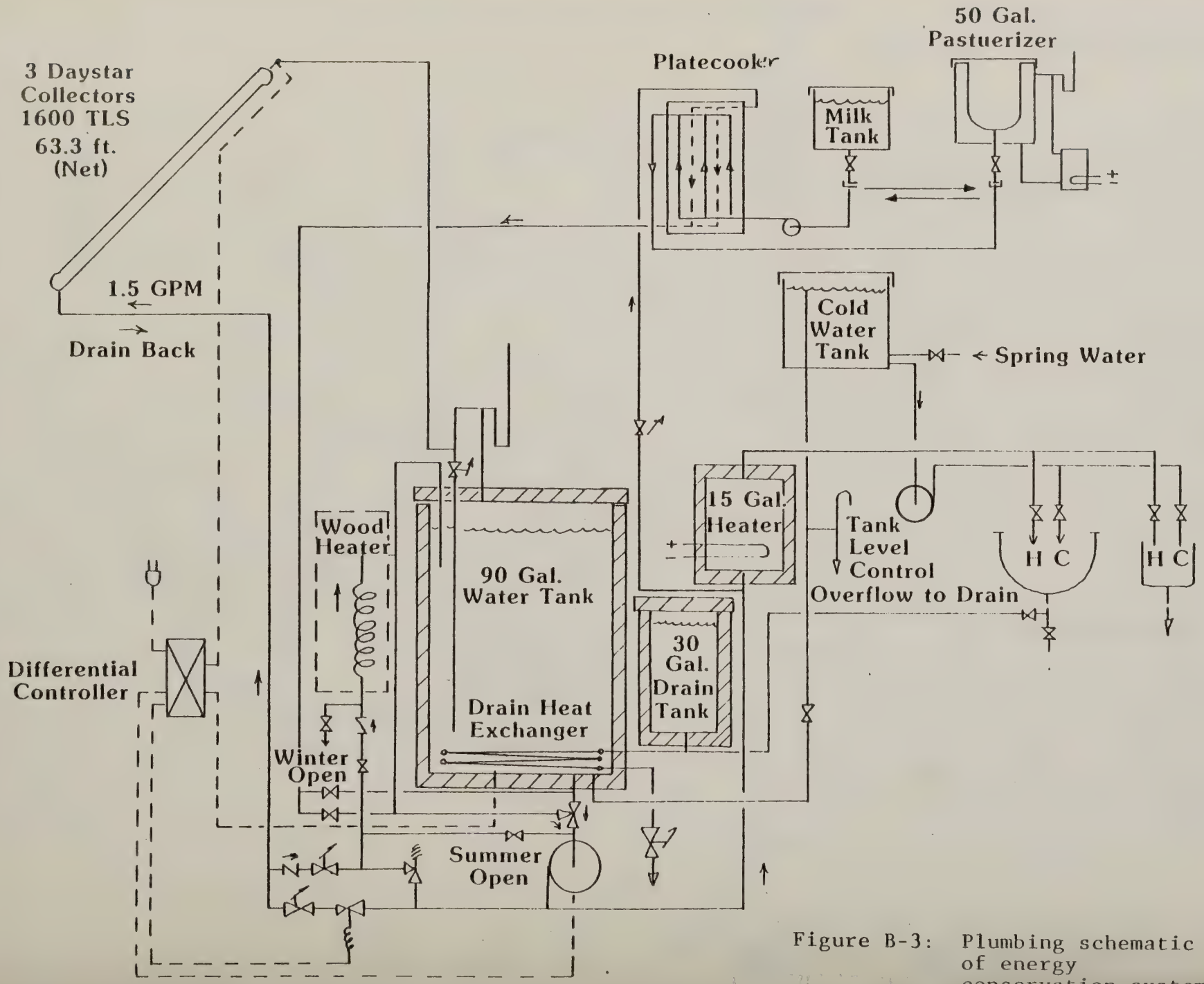


Figure B-3: Plumbing schematic of energy conservation systems.

SUMMARY

SOLAR DEMONSTRATION PROJECT C

Foster Brothers Farms, Inc.

Middlebury, Vermont

Cooperator: Foster Brothers

Location: Approximately 2.4 miles south of Middlebury and 0.6 miles east on Schoolhouse Road.

Farm business: Dairy; approximately 350 milking herd, 16,500 lb. rolling herd average; cultivating 900 acres; crops raised: corn, alfalfa, mixed hay.

Description of calf barn: An old milking center has been converted to a calf nursery with capacity of 28 calves 0-4 weeks of age. The structure is an old barn with no insulation. The walls are 3-core masonry block. It is a two story barn with a gambrel roof. The roofing is metal. The remodeled barn also includes a utilities room and a room for calves aged 1-6 months. Figure C-1 shows a plan view of these remodeled facilities. Solar is utilized to supplement the space heat required for the calf nursery.

SOLAR SYSTEM: The solar system contains two separate and independent parts. They are: a) retrofit ventilation air pre-heat with no heat storage, and b) passive thermal mass wall.

a). The lower slope of the existing south facing roof of approximately 430 sq.ft. was painted flat black and covered with one layer of glazing. The slope of this roof is approximately 60 degrees above the horizontal, ideal for a winter solar collector in this part of the country. Ventilation air is drawn between the glazing and roofing into the nursery ventilation system. Thus, the ventilation air is preheated when the sun shines. There is no storage associated with this part of the solar system.

b). The existing concrete block wall of approximately 300 sq.ft. was painted flat black and covered with two layers of glazing spaced 3/4 inch apart with 1x2 (nominal) furring strips. The block wall absorbs the sun's radiation, stores the heat for the short periods of time, and reradiates the energy into the calf nursery.

Figure C-2 exhibits a cross-section of the barn with solar systems attached.

Ventilation and back-up heat systems: A variable speed fan draws air from the solar system or directly from outside. A center duct distributes ventilation air to the calf nursery. An oil heater supplies back-up heat. See figure C-3 for an isometric of the air delivery system. Note that the ventilation air of solar system a is delivered to sweep the inside of the solar wall system b. Air ports between the nursery and the main calf barn (see figure C-1) allows air to pass from the nursery which has positive pressure ventilation, into the barn housing older calves, with negative pressure ventilation. Other than these ports, the room for the older calves has a separate ventilation and back-up heat system.

Cost: The total retrofit cost for this solar system was $3,358 or approximately $4.60 per sq.ft. of collector surface.

Performance: This solar system has supplied about 5.5 million Btu's total annually (2.5 from the roof and 3 from the wall). This replaces about 55-60 gallons of fuel oil each year.

Solar consultant for this project: Douglas Taff, Parallax, Inc., Hinesburg, VT.

Problems and suggestions for improved design: The furring strips separating the 4 mil teflon inner glazing from the wall and outer covering was not sufficiently thick to keep the teflon from plastering either to the concrete or outer covering in spots, thus effectively reducing the overall insulation value of the dead air spaces.

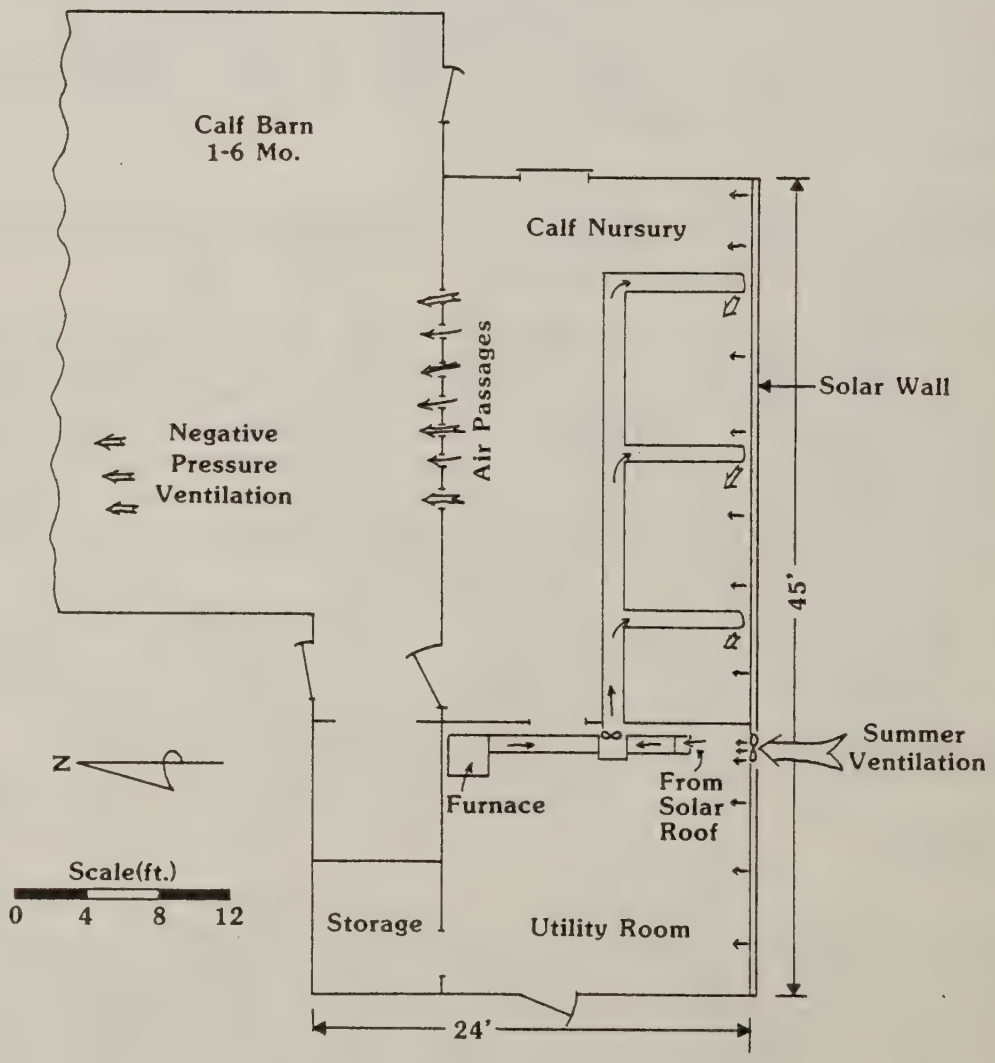


Figure C-1: Plan view of Foster calf facilities.

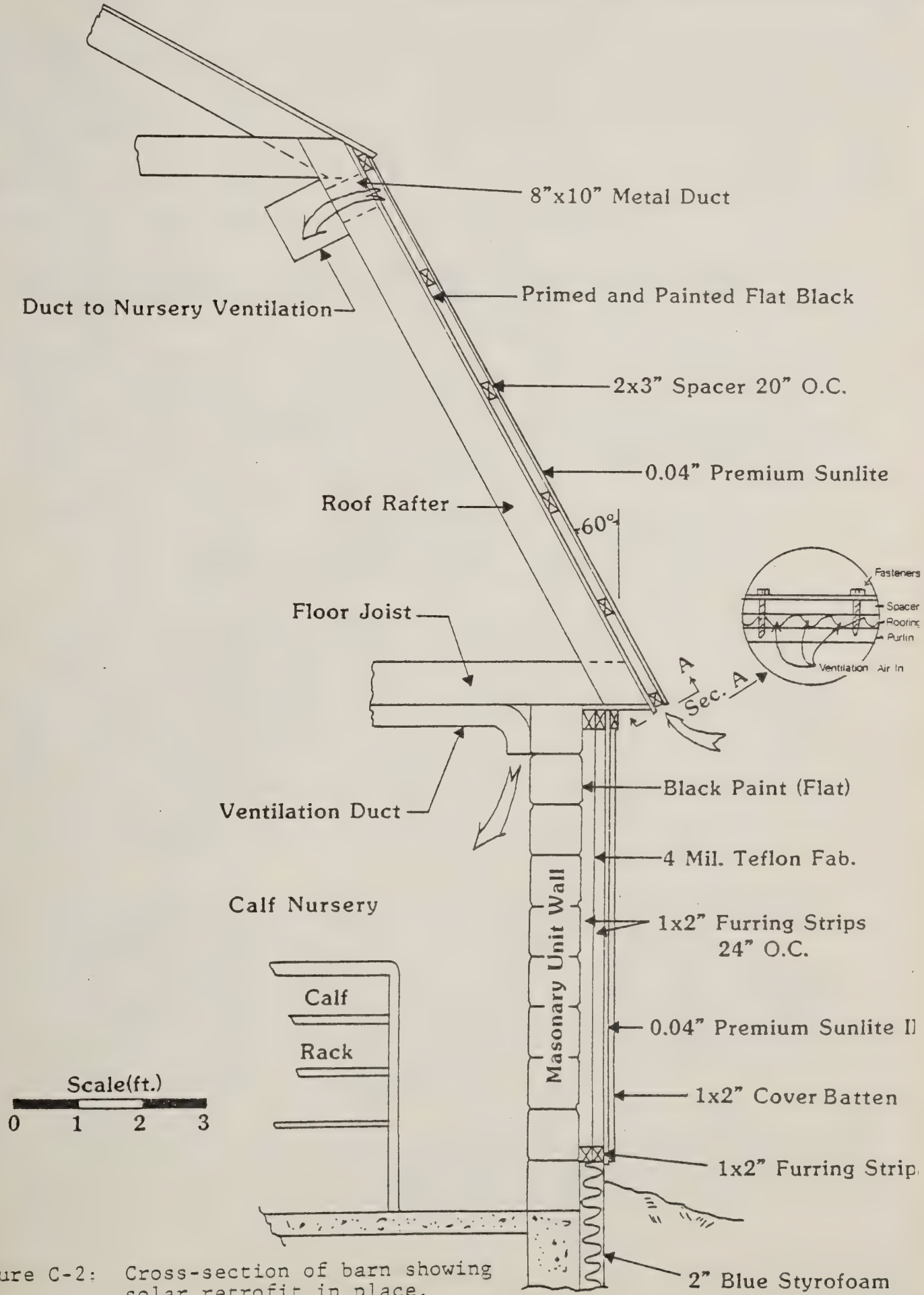


Figure C-2: Cross-section of barn showing solar retrofit in place.

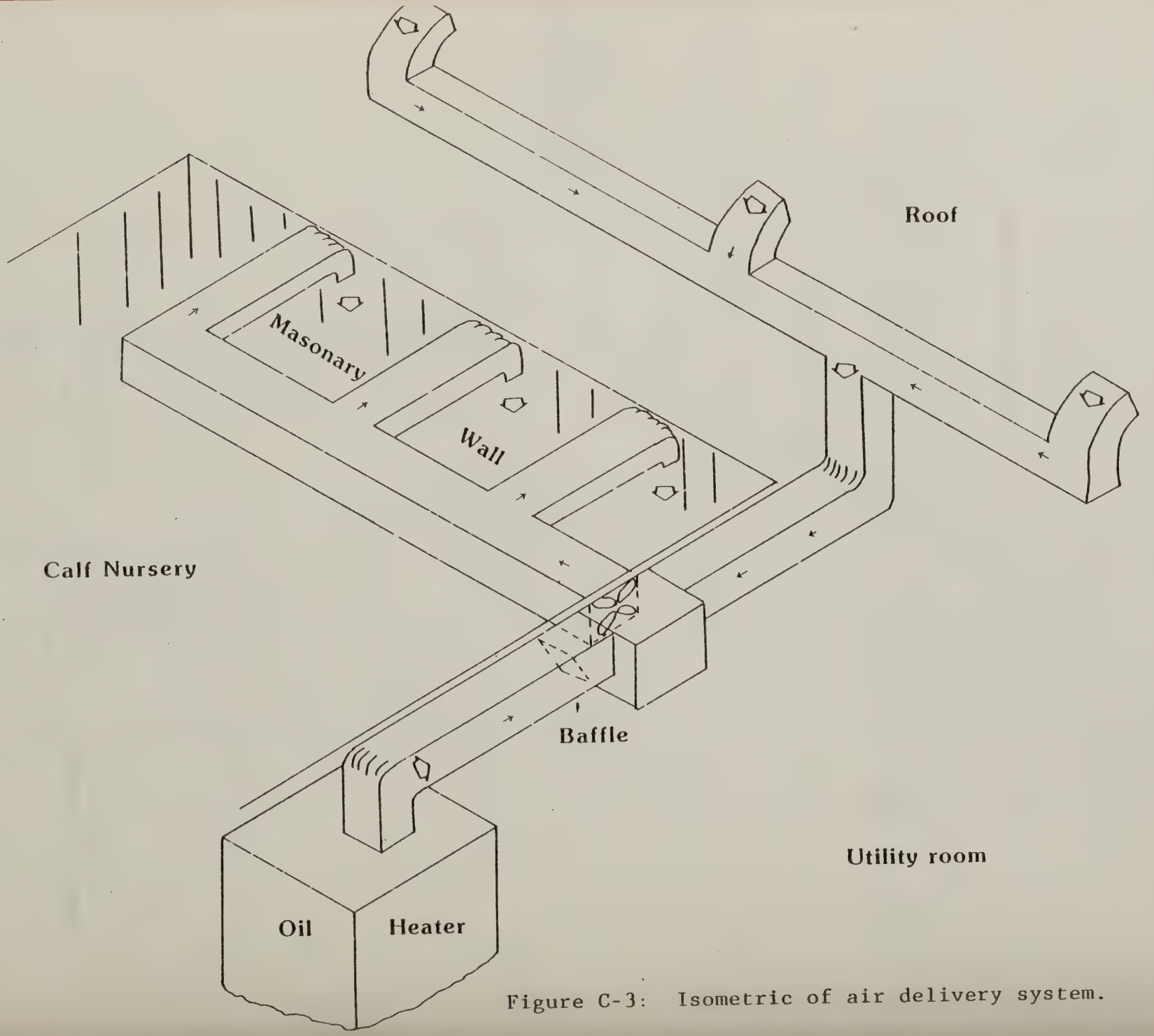


Figure C-3: Isometric of air delivery system.

SUMMARY

SOLAR DEMONSTRATION PROJECT D

Don-Sim Farm

Sutton, Vermont

Cooperator: Donald Simpson

Location: 1.4 miles southeast and 0.8 miles south of Sutton

Farm business: Dairy, registered Holsteins, approximately 200 head; milking approximately 100 head; cultivating 250 acres; crops raised: corn and alfalfa.

Description of calf barn: 24x50 feet, new construction, completed August 1979. The pen layout and air delivery system is shown in figure D-1. Capacity: 40 calves from birth to about 4 months of age. Six-inch stud frame wall construction and truss rafters were used. Two hundred square feet of solar collector/storage to preheat ventilation air was built into the south end of the building.

Insulation:		
Walls:	6" fiberglass,	approximate R = 20
Ceiling:	12" fiberglass,	approximate R = 36
Windows:	double pane,	approximate R = 2
Perimeter:	1½ inch polystyrene,	approximate R = 6

SOLAR SYSTEM: A solid-core concrete block wall (16" deep) with southerly exposure was used for solar heat collection and storage. Two layers of fiberglass reinforced polyester cover sheets were used to reduce heat loss to the outside environment. Perpendicular openings between the blocks, and the spacing between the cover sheets allow outside air to be drawn through the block wall and into the plenum behind the wall, as shown in figure D-2, and from there into the barn. The sun heats the block wall (painted black) and the heat is picked up by the air as it passes through the wall. Actually, in this case air is drawn in through the attic instead of directly from outside, which provides some additional preheat.

Ventilation and backup heat: The ventilation system is a positive pressure system as fans force air through a distribution duct into the barn. For temperature control and summer ventilation, a variable speed fan delivers outside air to the duct as shown in figure D-3. A 24,000 Btu/hr propane LP gas heater is used as a backup heat source. Thermostats control the operation of the gas heater and the large variable speed fan. The smaller, "solar" fan runs at a constant speed and is controlled manually. It is designed to deliver the base quantity of air required to control mositure levels during the winter.

Cost: The cost of materials for the solar collector alone was $860. The total installed cost including labor and added structural costs to the building is estimated at $2,040. It is estimated that annual maintenance and operation costs will, on the average, be less than $20 per year.

Performance: Two winters of monitoring show that this solar system will save approximately 7-8 million Btu's annually. This is approximately 100 gallons of LP gas that will not have to be purchased. Figure about 1/2 gallon saved per sq.ft. of collector. The solar wall has supplied about 90 percent of the total heating needs for this building.

Design source: The design of this solar system was based on a similar system developed at Kansas State University for solar heating of swine farrowing houses in the Midwest.

Problems and suggestions for improved design: When the solar fan is in operation, it puts a back pressure on the gas heater, often blowing out the pilot light. The gas heater should deliver heated air behind the solar fan, perhaps directly into the solar plenum between the solar and barn walls.

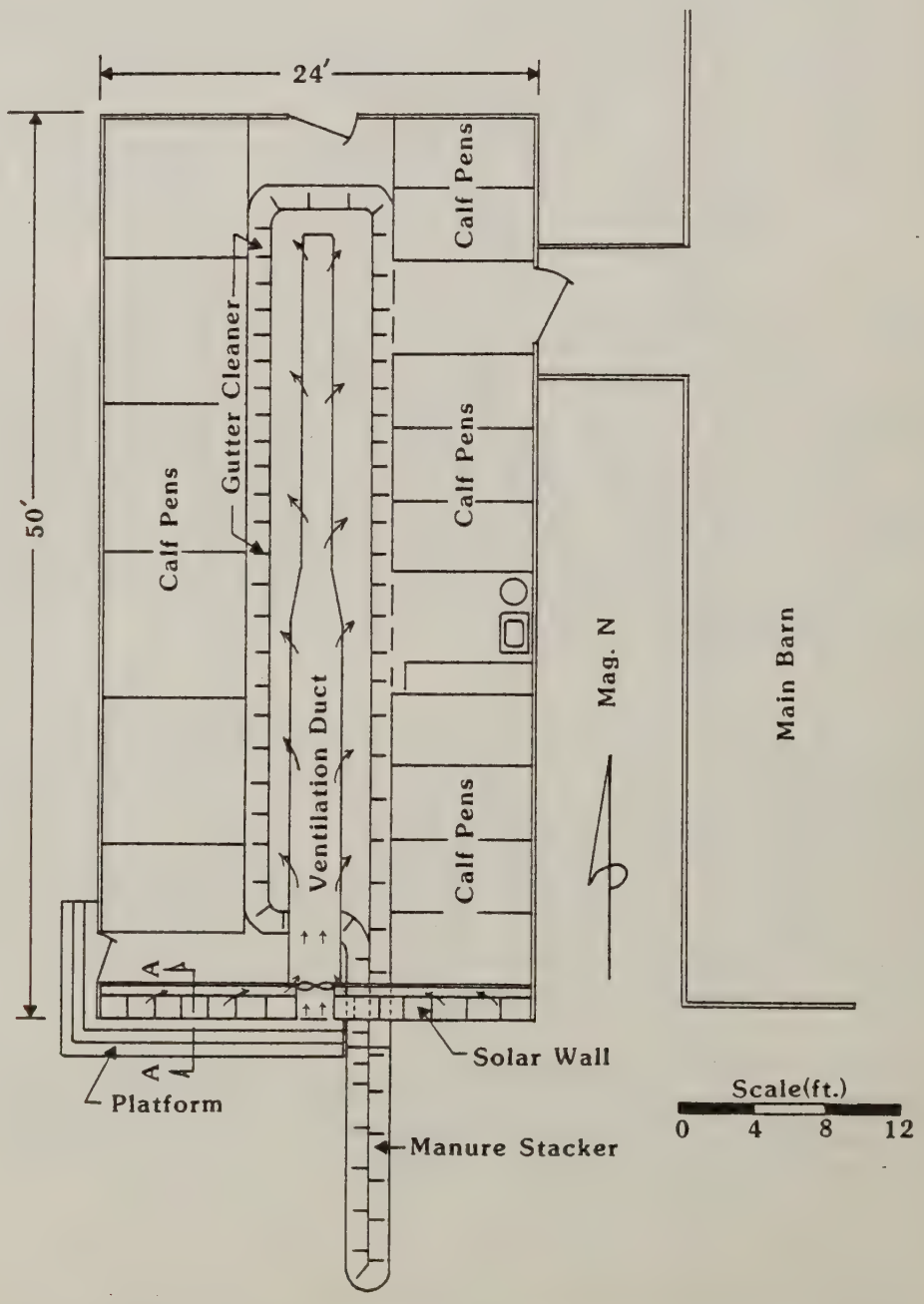


Figure D-1: Plan view of Simpson's calf barn.

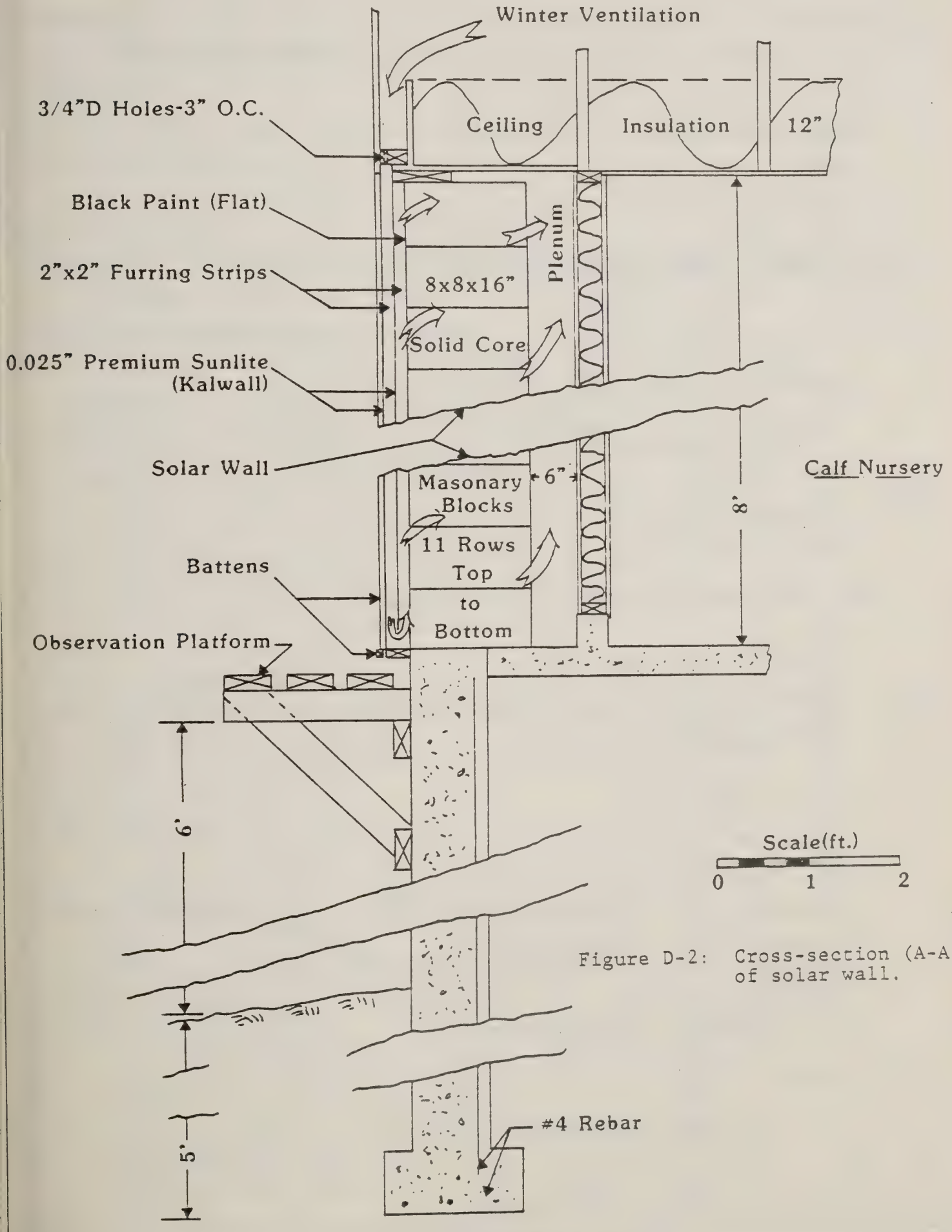
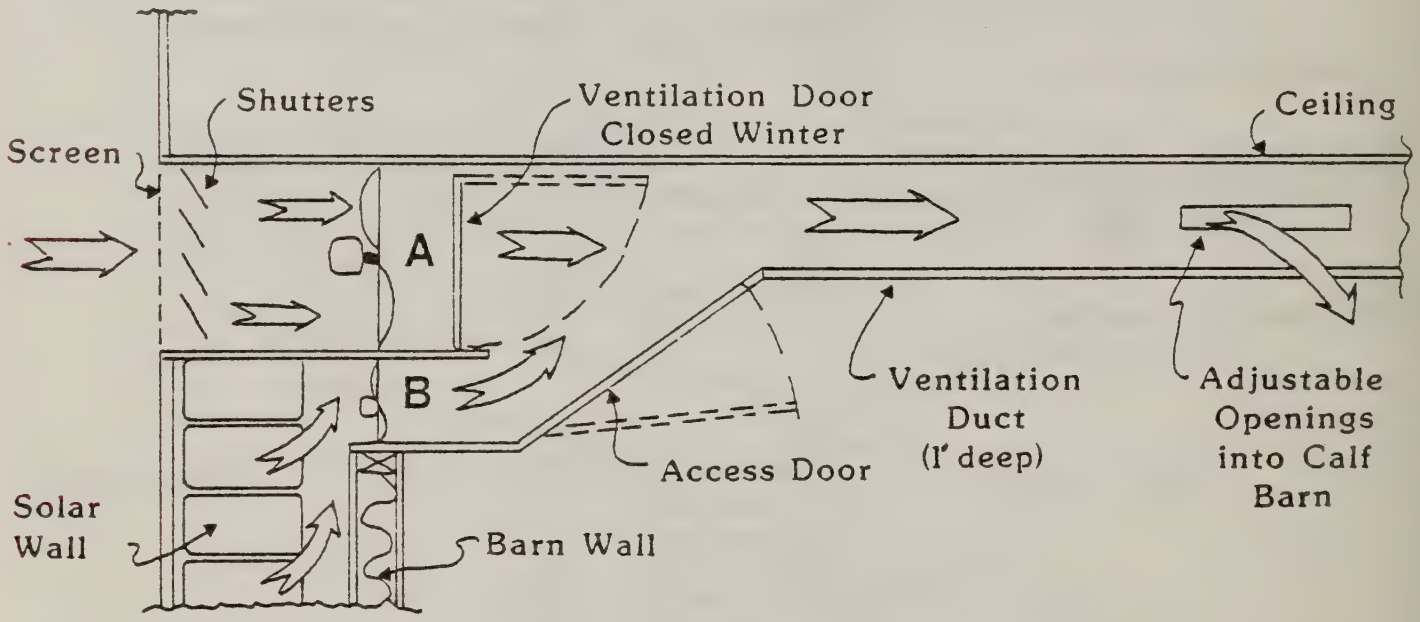


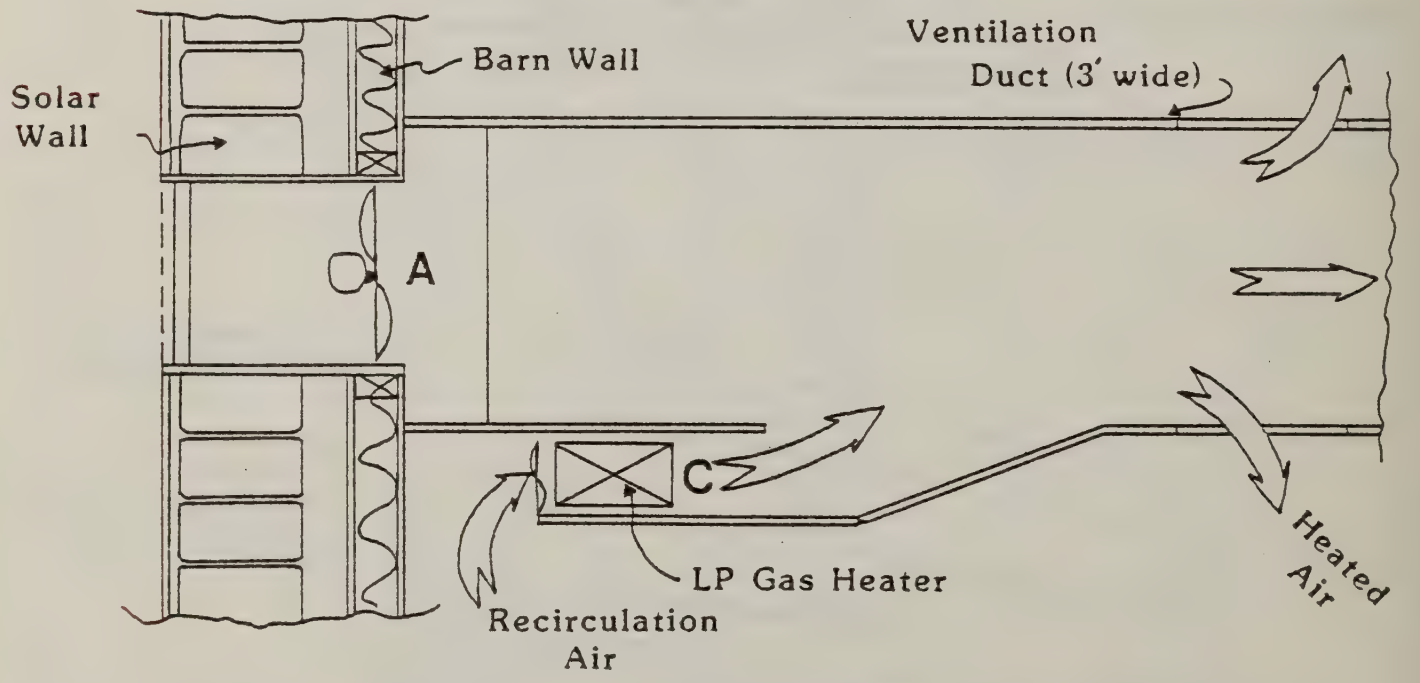
Figure D-2: Cross-section (A-A) of solar wall.

Figure D-3: Air and heat delivery systems detail.

VERTICAL SECTION (side view) showing ventilation fans.



HORIZONTAL SECTION (top view) showing heater.



Notes:
A. Summer ventilation and temperature control -- 18" variable speed fan draws air directly from outside.

B. Winter ventilation for moisture control -- 10" single speed fan in barn wall below A draws air through solar wall.

C. Heater -- mounted on the side of the duct and recirculates heated air into the duct.

SUMMARY

SOLAR DEMONSTRATION PROJECT E

Visser Farm

Addison, Vermont

Cooperator: Raymond Visser

Location: Jersey Road, approximately 4 miles south and 1/2 mile west of Panton, VT.

Farm business: Dairy veal calves; 236 pens (calf racks): approximately 700 sold annually. See figure E-1 for layout.

SOLAR SYSTEM: The solar system used here is an active, liquid based, closed loop water heating system, preheating water to be used for mixing calf feed. Mixing temperature is about 160 deg. F. The collector, site-built, consists of approximately 300 sq.ft. of synthetic extruded rubber material (EPDM), mounted on a rack with 45 degree tilt leaned against the south end of the barn as shown in figure E-2. Copper headers were used, and 200 feet of copper pipe to carry the collector fluid from collector to heat exchanger in feed room was required. The storage tank is a used bulk milk tank, 500 gallon capacity, non-pressurized, boxed and insulated by 6 to 12 inches of fiberglass. 160 sq.ft. of heat exchanger surface outside the storage tank is used to transfer heat from collector fluid to water. A non-toxic antifreeze solution is used as the collector fluid. Figure E-3 contains a sketch of the plumbing.

A 40 psi shallow well pump with 12 gallon pressure tank is used to pump water from storage tank through back-up oil fired water heater and to point of use. The storage tank is manually filled once a day after morning feeding of calves to take full advantage of the solar day. Total heat requirements for feed water is approximately 107 million Btu's annually.

Cost: The total installed cost of this solar system was $7,559 or $27.20 per sq.ft. of collector. Energy required for operating the pumps to circulate water and collector fluid have been measured to be about 1,000 kw-hr per year. Total operational and maintenance costs of this system will probably be about $80 per year.

Performance: This solar system has been monitored for 2 years. This system has contributed about 36 million Btu's of useful heat per year, about 121,000 Btu's per sq.ft. of collector. This replaces about 360 gallons of fuel oil per year. This system converts about 28% of the total solar radiation received at this site into useful heat energy. Thirty-four percent of the total water heating requirements are supplied by solar.

Solar consultant for this project: Douglas Taff, Parallax, Inc. Hinesburg, VT.

Solar contractor: Frederic Lowen, Gentle Energy Systems, New Haven, VT.

Problems and suggestions for improved design: Several leaks developed in the rubber material immediately after start-up. It took more than a half a year to find and stop all leaks. There has not been much problem with leaks for the last year and a half.

A fiberglass reinforced polyester was used as glazing material over the collector. Support straps were placed 3 feet apart. They should have been placed no more than 2 feet apart. The glazing will probably have to be completely reinstalled in a couple of years.

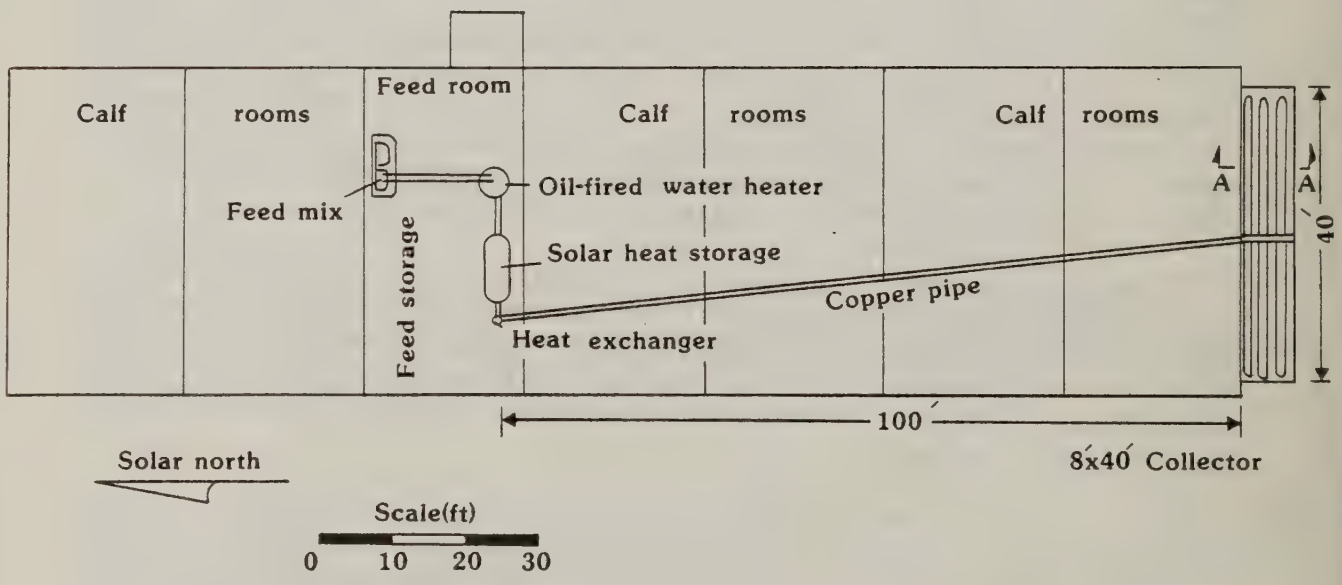


Figure E-1: Plan view of Visser veal calf barn.

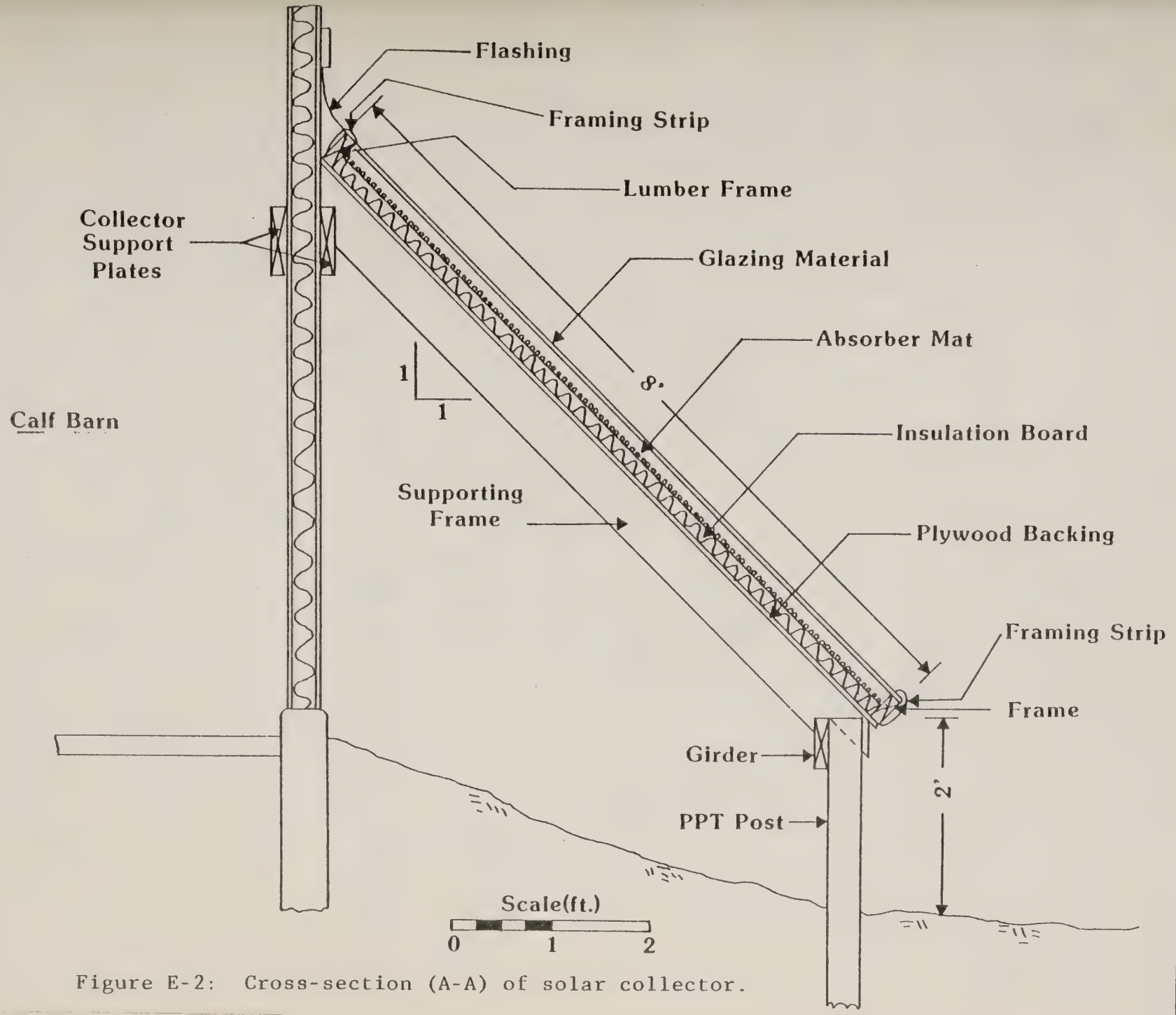


Figure E-2: Cross-section (A-A) of solar collector.

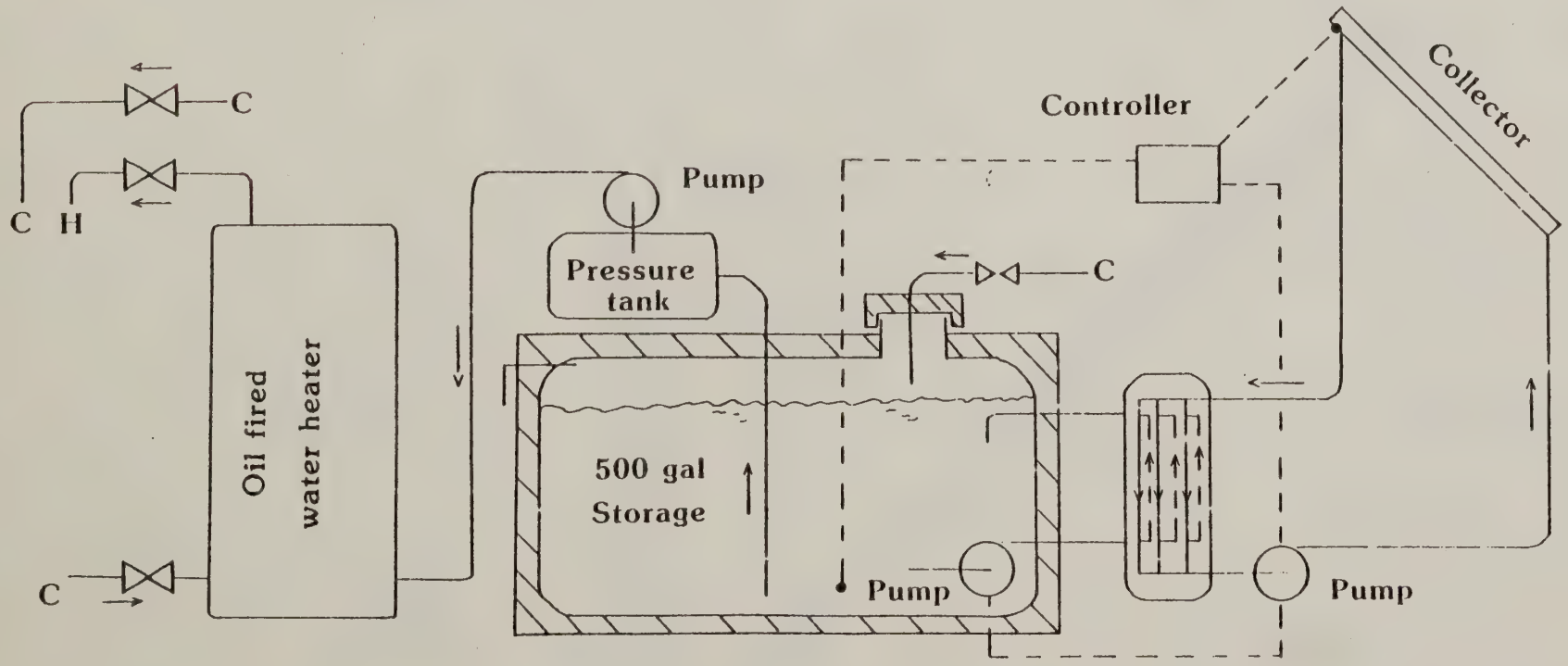


Figure E-3: Plumbing schematic of Visser solar system.

SUMMARY

SOLAR DEMONSTRATION PROJECT F

McReynolds Farm

Danville, Vermont

Cooperator: Everett and Martha McReynolds

Location: About one mile north of the village of North Danville on a country road.

Farm business: Dairy; milking about 75 Jerseys and farming about 250 acres.

Description of calf barn: 24x40 ft. with a 8x37½ ft. solar wall on the south side and a 14x27 ft. hay/bedding storage on the east end. See figure F-1 for barn layout with calf pens, stalls, and feed area. Barn capacity is 30-35 calves from birth to about 4 months. Insulation includes 6 inches in the walls and 12 inches above the ceiling.

SOLAR SYSTEM: 300 sq.ft. of solar collector/storage wall to preheat ventilation air before it enters the calf barn. This provides supplemental heat to the calf nursery. This system uses concrete blocks made on the farm. The solid blocks were poured in 12x18x24 inch forms. The 18x24 inch sides of the block, painted black, face south. The vertical joints between the blocks were left open for air passage. Figure F-2 shows a cross-section of the solar collector/storage unit and Figure F-3 illustrates the air flow through the solar wall. Temperature rise in the plenum chamber behind the solar wall has been recorded to be as much as 25 degrees above outside temperature.

The calf barn is not used during the summer months. Doors at each end of the plenum chamber are opened during the summer or when excessive heat is being drawn into the barn (spring/fall) through the block wall. This allows ventilation air to bypass the solar wall and keeps the solar wall from overheating in the summer.

Ventilation and back-up heat: A two-speed fan exhausts air from the barn creating a negative pressure inside. Air comes into the barn through a slot after passing through the solar wall. The fan capacity is 500/2000 cfm, about 15/50 cfm per calf and 1½/7 cfm per sq.ft. of solar wall. Thirty feet of baseboard electric heater (750 watts total capacity) is located on the south wall about one foot below the slot inlet. The electric heaters are controlled by thermostats in two steps. The high speed of the fan is also controlled by a thermostat.

Cost: The total installed cost of this solar system was $2,799 in 1980. Ninety-six man-hours of labor were required. The collector/storage unit cost based on 300 sq.ft. is $9.33. No operation or maintenance costs have been recorded so far.

Performance: 12 million Btu's (3,500 kw-hr) have been contributed by this solar system to heating of the calf barn. This was about 80% of the supplemental heating required to maintain the nursery at temperatures of 46 deg. F. or above.

Design source: This system design was based on the design of Vermont solar project D and the Kansas State University design for a solar heated swine farrowing house.

Problems and suggestions for improved design: Air is drawn into the solar wall from the attic and along with the air comes some dust from bedding storage area. There is evidence of dirt build-up on the inside of the glazing. The advantage of the 1 or 2 degree temperature rise from the attic may soon be offset by reduced transmittance of the glazing due to dirt accumulation on the glazing. In this case, it is felt that the air should not be drawn through the attic.

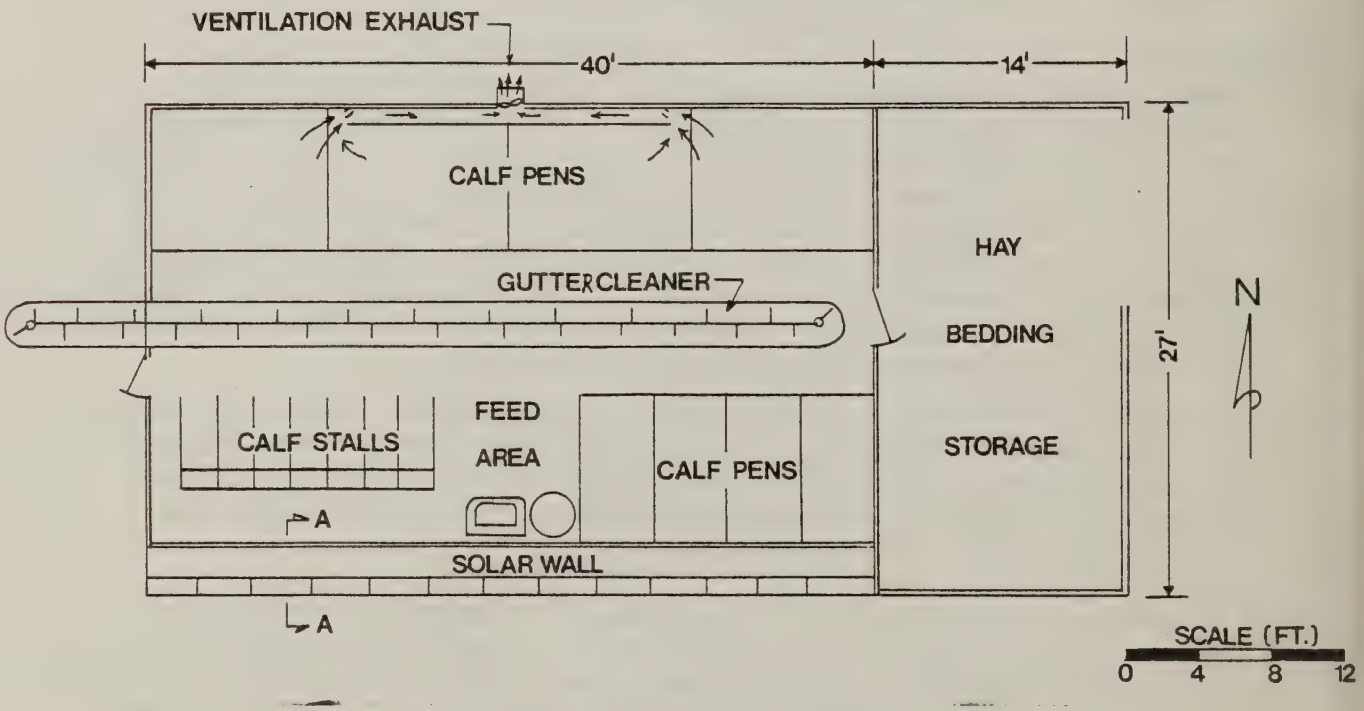


Figure F-1: Plan view of McReynold's calf barn.

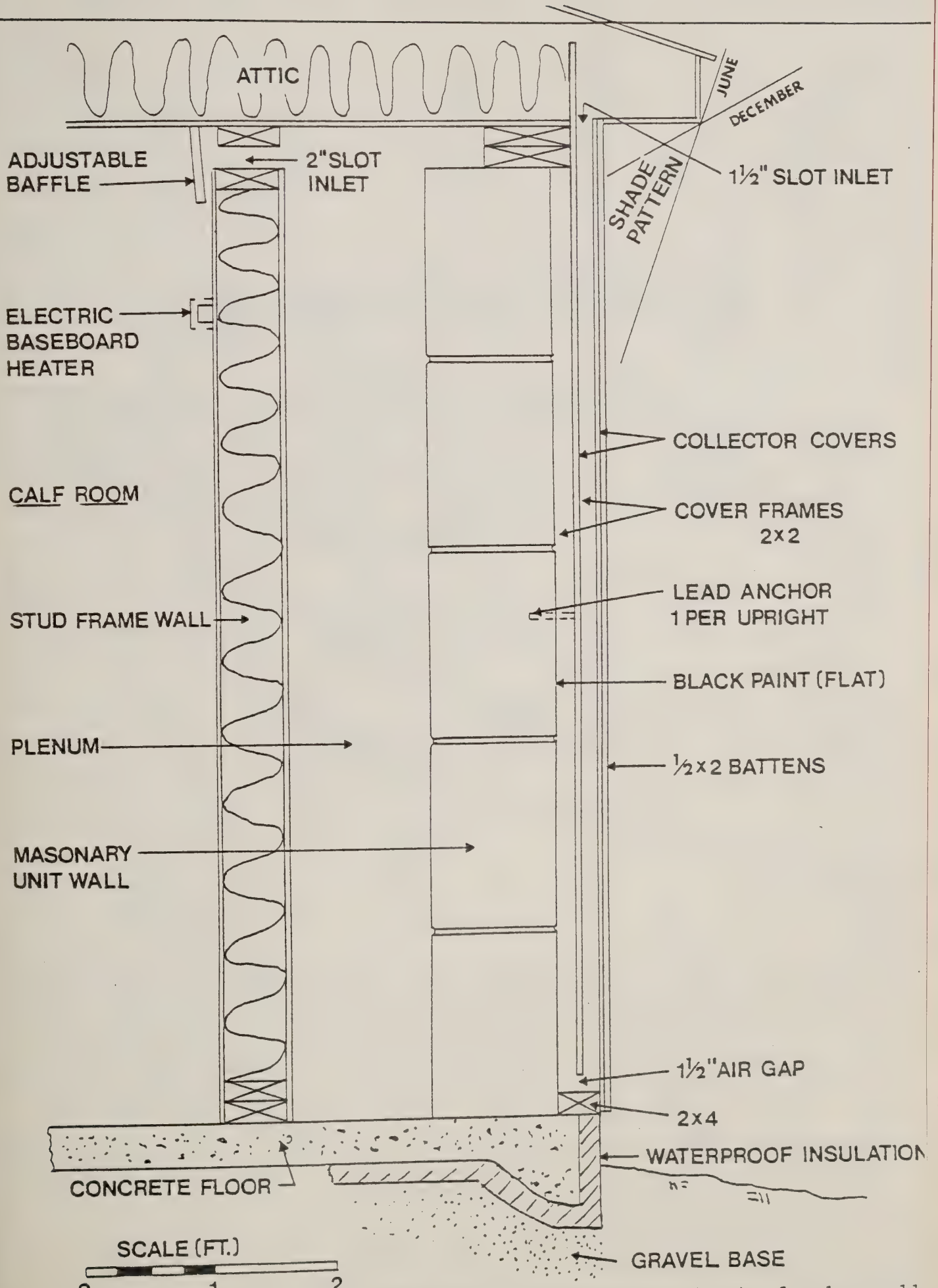


Figure F-2: Cross-section (A-A) of solar wall

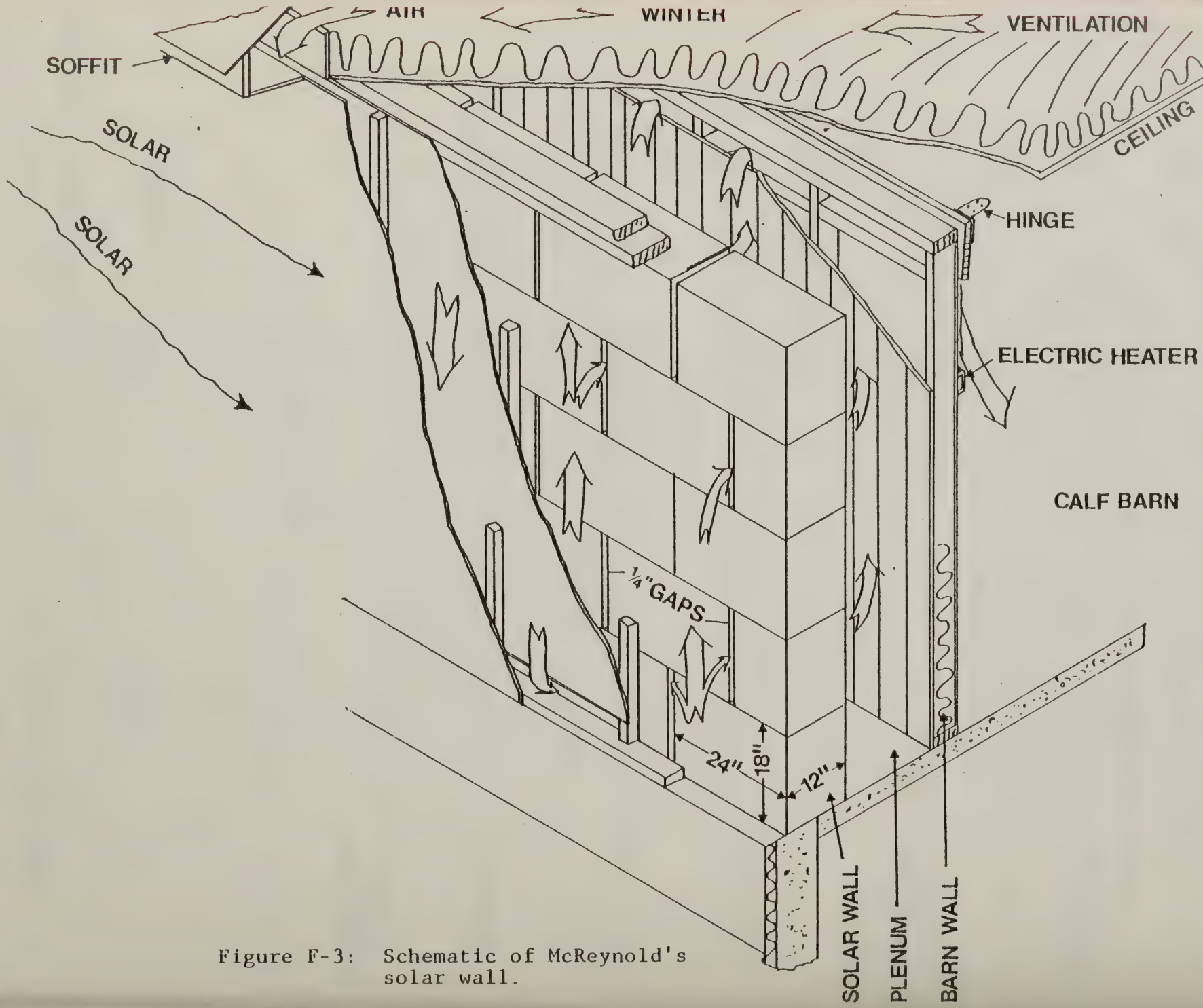


Figure F-3: Schematic of McReynold's solar wall.

SUMMARY

SOLAR DEMONSTRATION PROJECT G

Maple Meadows Farm

Salsibury, Vermont

Cooperator: George Devoid

Location: Salisbury Village, VT.

Farm business: Poultry, eggs, and vegetables; approximately 26,000 layers; raise own pullets; wholesale egg route; wash, grade and package approximately 40,000 cases of eggs annually. See figure G-1 for general egg processing layout.

SOLAR SYSTEM: The solar system is an active, liquid-based closed loop water heating system for egg washing, rinsing, and clean-up operations. The collector is approximately 140 sq.ft. of synthetic extruded rubber (EPDM), site-built, roof mounted on a rack with a 45 degree tilt to the horizon as shown in figure G-2. Two standard 120 gallon pressurized solar storage tanks were used to store the solar heated water. Each tank contains 40 sq.ft. of heat exchanger surface. Tanks and plumbing are shown in the plumbing schematic of figure G-3.

Back-up heat: Back-up heat is supplied by an oil-fired furnace which can supply all the space and water heat needed for the operation. It is estimated that 60 million Btu's of heat is required annually to heat water for egg washing and rinsing.

Cost: The installed cost of this solar system was $5,591 (in 1980), or approximately $37.28 per sq.ft. Operational costs include the electricity used to operate the circulation pump of the solar system. Measurements show that this will be about 340 kw-hr per year.

Break down of installation costs (approximate):

collector	$1,600
storage	1,200
plumbing	1,050
building materials	350
contracted labor	1,400

Performance: Measurements show that this solar system supplies approximately 17 million Btu's of useful heat to the egg washing operation each year. This means the solar system replaces about 170-200 gallons of fuel oil each year, about 1-1/4 gallons per sq.ft. of collector. This is a little less than normally expected. However, at this site, water is used only 5 days out of 7 and the collector is facing 30 degrees west of true south. (See figure G-1).

Solar consultant for this project: Douglas Taff, Parallax, Inc., Hinesburg, VT.

Solar contractor: Green Mountain Energy Systems, Middlebury, VT.

Problems and suggestions for improved design: The cooperator has not been able to maintain operating pressures with this system. It operates at about 5 psi instead of 18 psi as recommended. Apparently there is a small leak that cannot be located without purging the entire system.

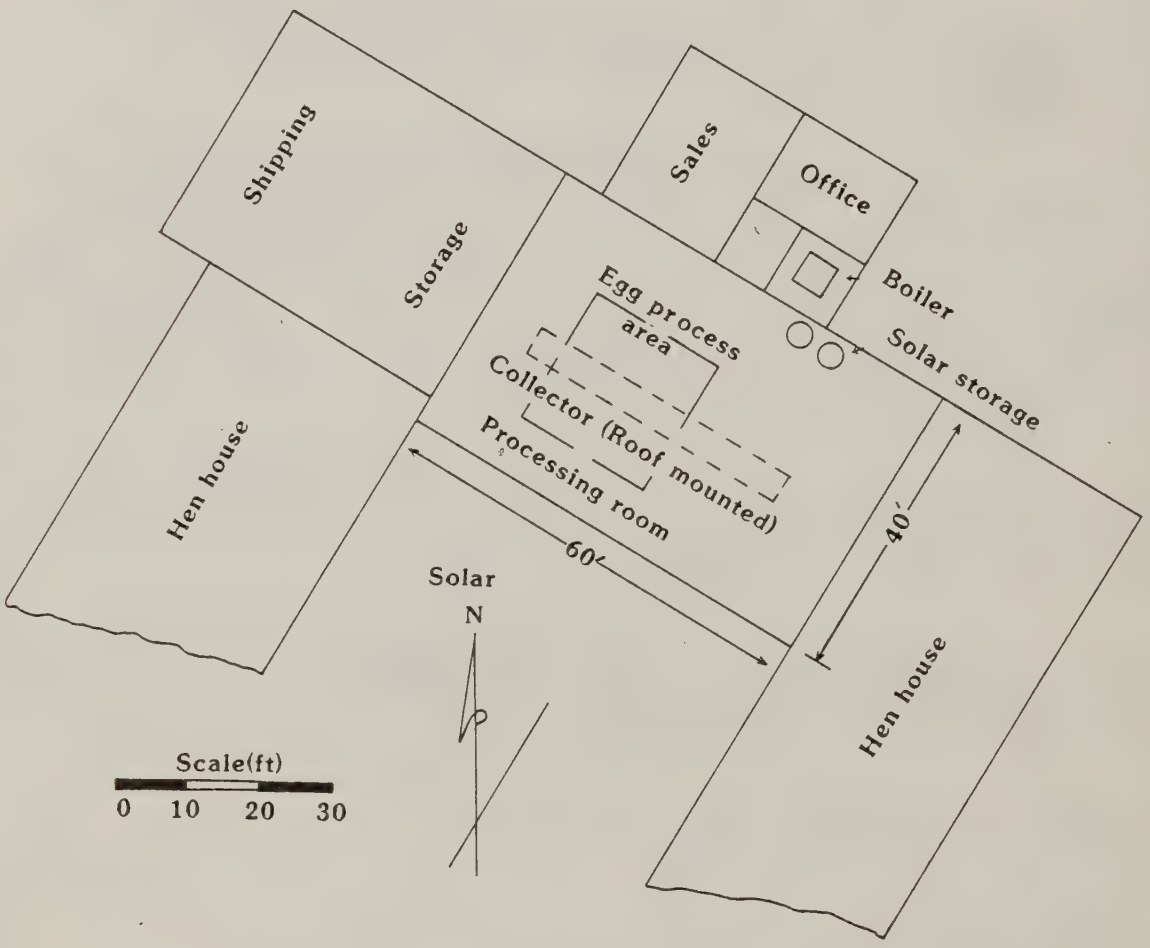


Figure G-1: Plan view of Devoid's egg processing facilities.

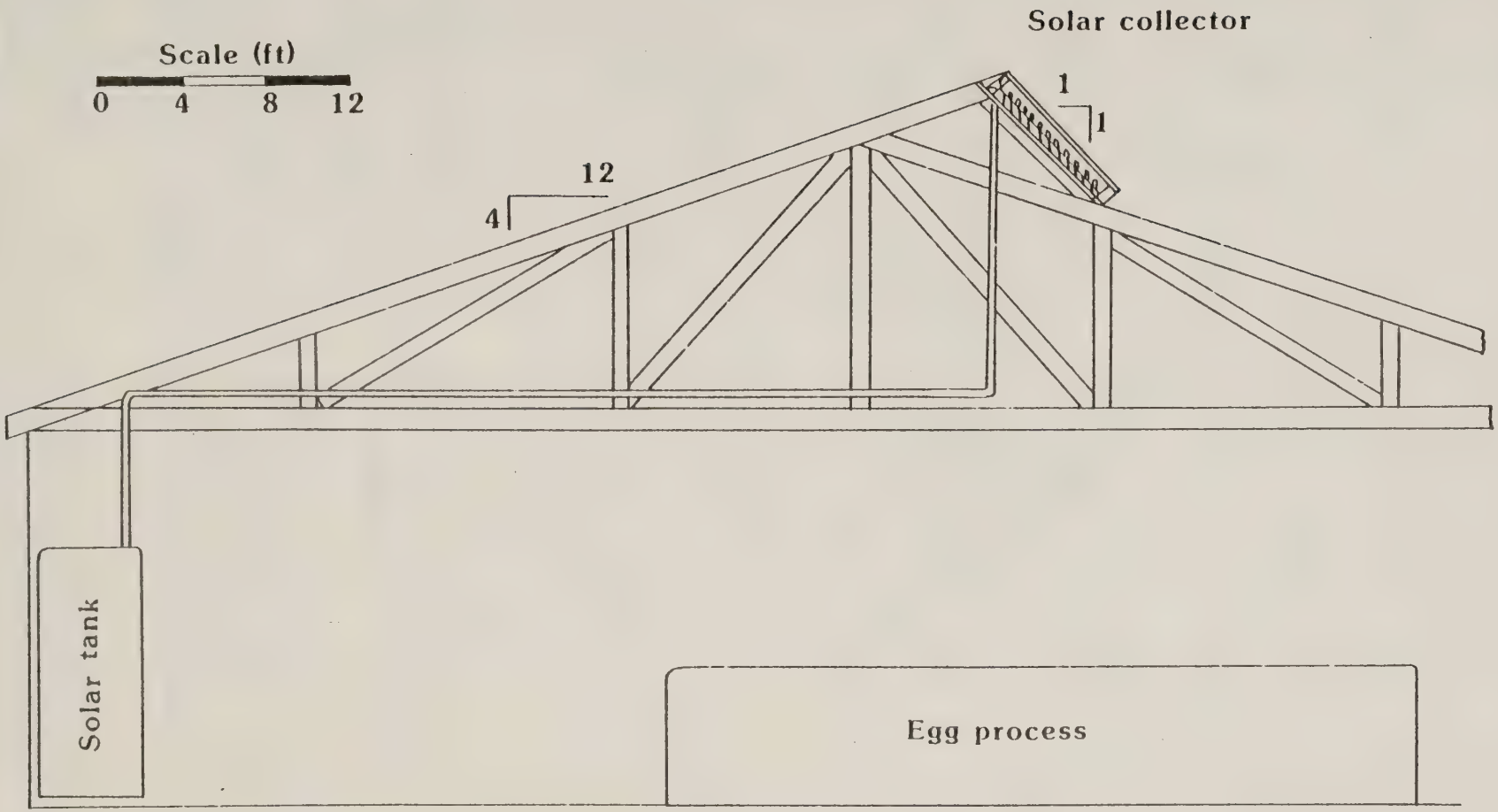


Figure G-2: Cross-section of Devoid's solar system.

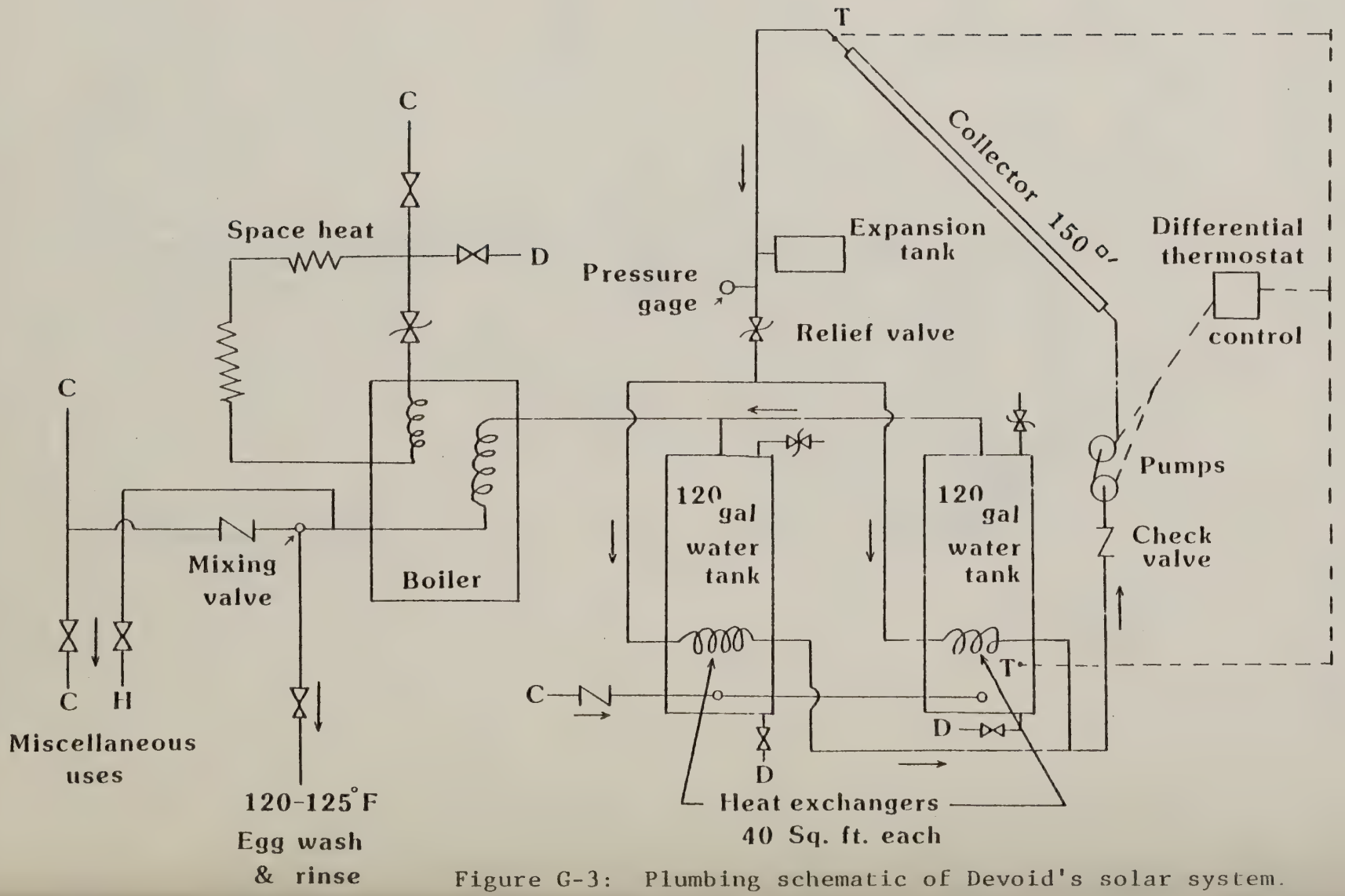


Figure G-3: Plumbing schematic of Devoid's solar system.

SUMMARY

SOLAR DEMONSTRATION PROJECT H

Small Meadows Farm

Putney, Vermont

Cooperator: Earthbridge Community Land Trust

Location: Approximately 1 mile north of Putney Village on Rt. 5.

Farm business: Mixed livestock (dairy cattle, horses, sheep, and poultry) and garden produce; own 106 acres, till 20 acres; raise hay and garden vegetables.

Description of barn: The barn is 26x42 feet with a 3-foot second story overhang to the south. A 10x10 foot utility and milk room is located in the southwest portion of the barn. The barn is utilized to house several different species of livestock and poultry. The barn is set into the earth on the north and west sides. The exposed eastern wall is insulated. Solar applications include three separate and independent systems as shown in Figures H-1 and H-2. They are a solar greenhouse attached to the barn to provide supplemental heat to the livestock housing area, a breadbox water heater in the southwest corner of the greenhouse to preheat water for use in cleaning up milking utensils, and a thermosiphoning mass wall to heat the milk room.

SOLAR SYSTEM: An 8x27 ft. greenhouse supplements heat needed in the livestock shelter area to maintain the barn at temperatures above freezing. Approximately 200 sq.ft. of double walled extruded acrylic has been placed at a 55 degree tilt to the horizon. A rack along the back wall holds about 100, one-gallon plastic jugs filled with water. Black dye has been used to color water black. This water acts as a thermal storage. The greenhouse is also used to extend the growing season. Movable insulation helps retain the heat at night.

A 30-gallon drum in the southwestern corner of the greenhouse is used to preheat water for use in the milk room. The drum is contained in a tight insulated box with a cover that can be closed at night and on cloudy days. Figure H-3 shows a cross-section of the greenhouse through the breadbox water heater.

The 55 sq.ft. thermosiphoning mass wall supplies heat to the milk room. One way vents allow the air to circulate in the proper direction. Two layers of fiberglass reinforced polyester glazing are used. These layers are mounted on a frame that can be removed from the wall so that the entire wall can be exposed for natural cooling during the summer. See figure H-4 for further details.

Ventilation and back-up heat: Ventilation occurs by natural convection through the barn. Heat from the greenhouse circulates into the barn by natural convection. Electricity is used as back-up heat when absolutely necessary. A 1/2 gallon quick recovery electric water heater is used as a back-up heater for water.

Cost: The approximate cost for the total system including labor for installation was $2,880.

Performance: It is estimated that this solar system will supply approximately 7 million Btu's as space heat and 1 million Btu's for heating water annually. This is approximately equivalent to 80-90 gallons of fuel oil or approximately 2,000 kw-hr of electricity. Although all the space heat supplied by solar is not absolutely necessary for animal production, it will help to maintain a more pleasant and healthy environment in a space where there is insufficient animal heat to do so.

Added comments: The solar greenhouse is used for growing bedded plants in the spring. Approximately another 7 million Btu's of useful heat is obtained from the system for this purpose.

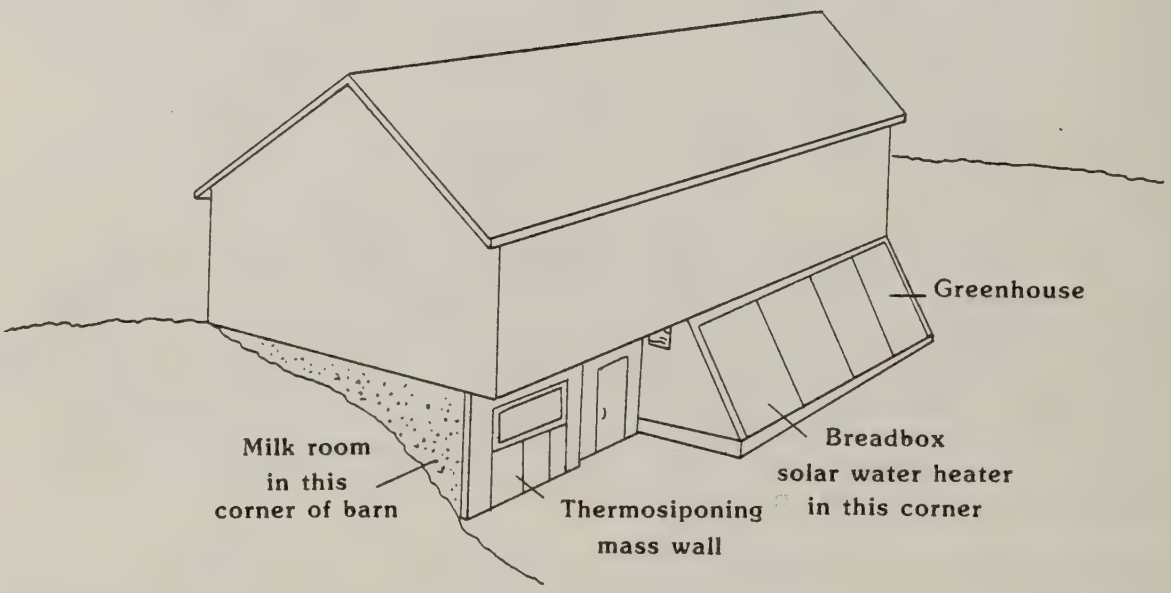


Figure H-1: Isometric of Small Meadows livestock barn and solar system.

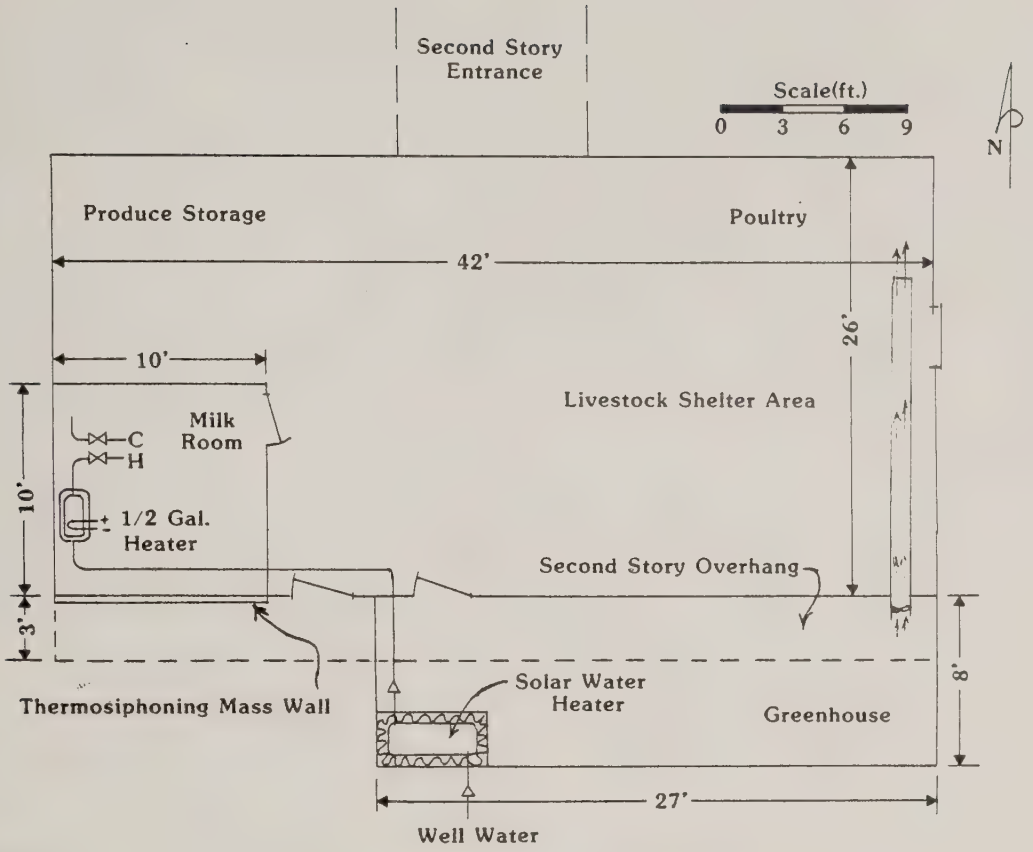


Figure H-2: Plan view of Small Meadows livestock barn and solar system.

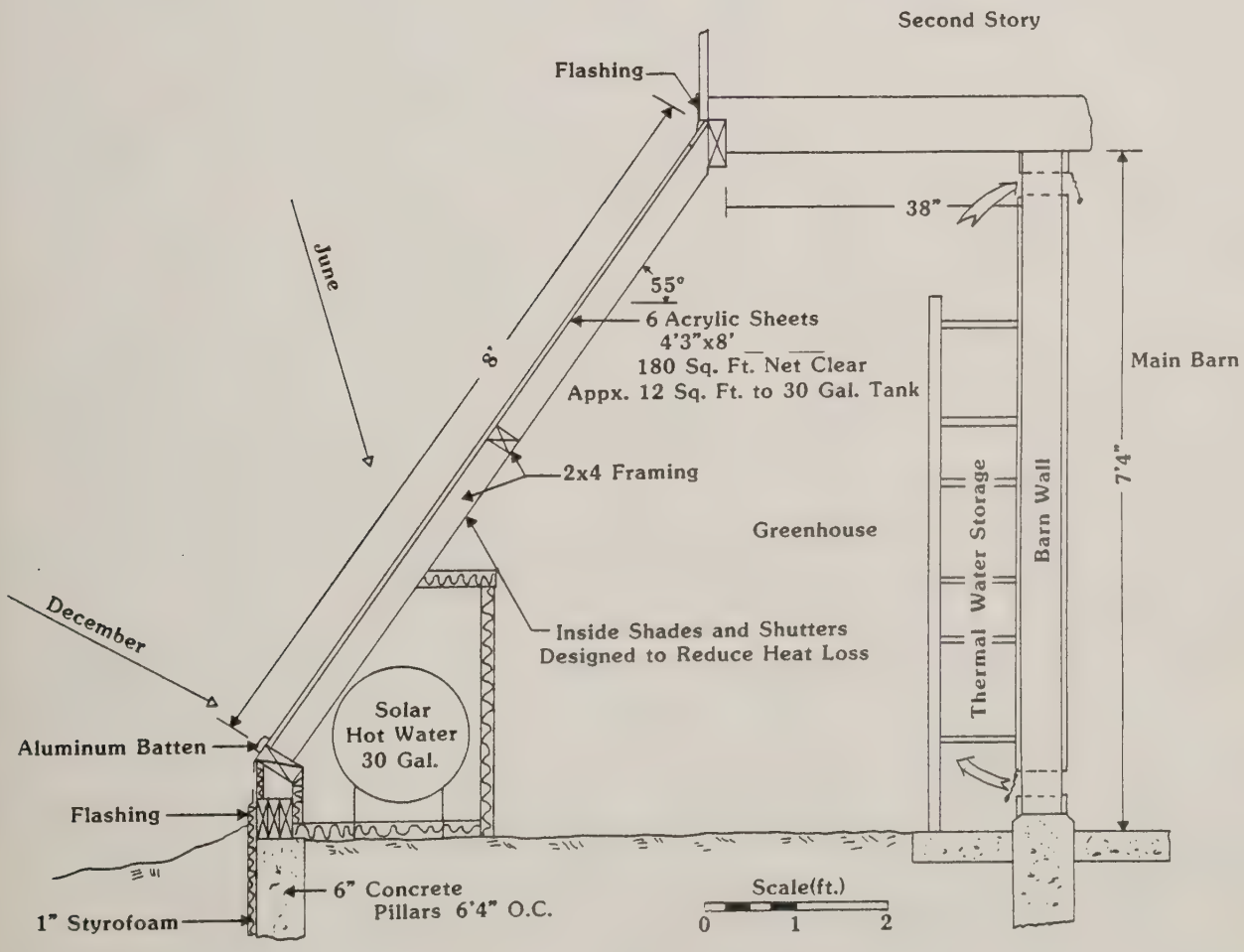
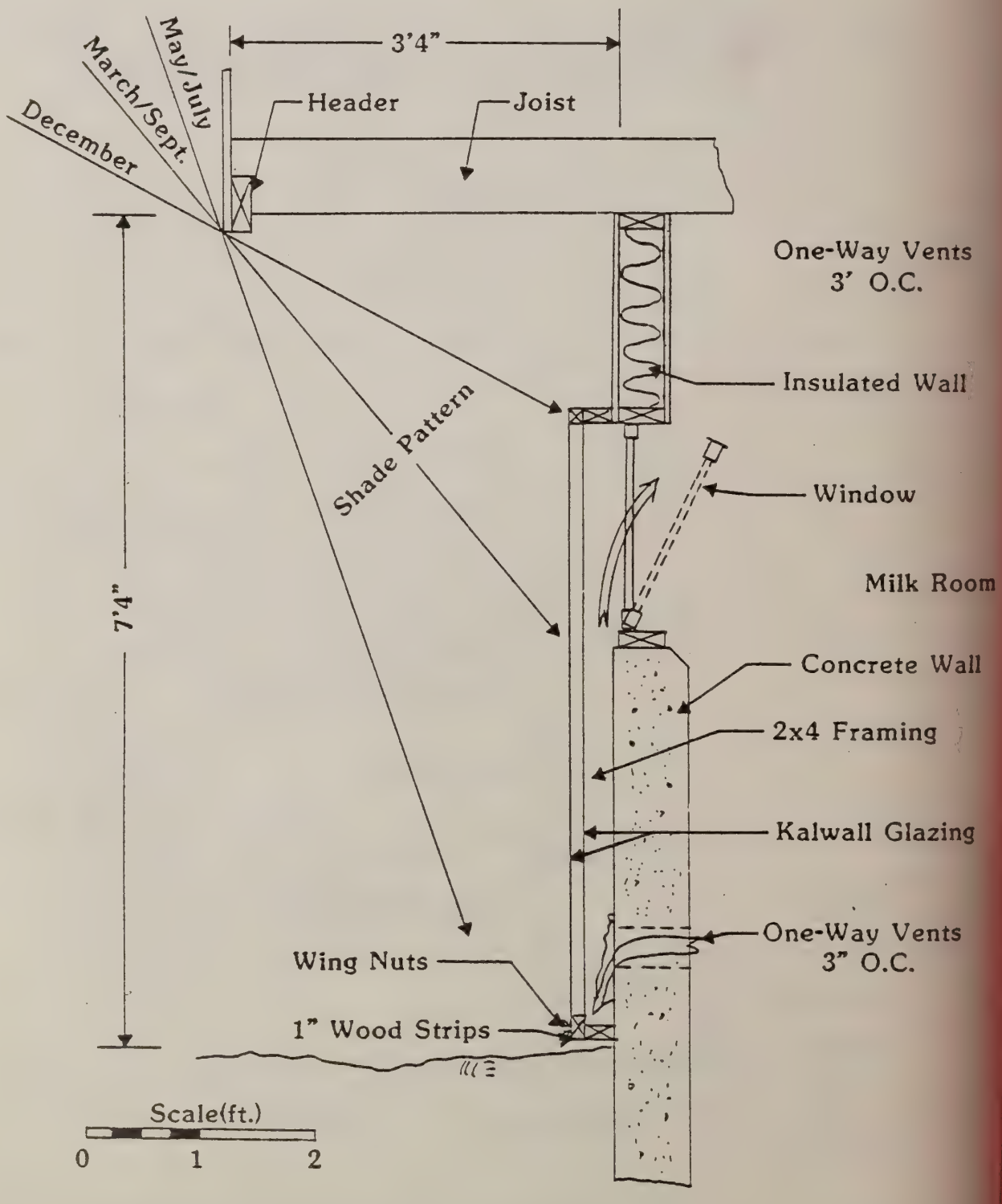


Figure H-3: Cross-section of greenhouse and breadbox water heater.

Figure H-4: Cross-section of thermosiphoning wall.



Final Report

DEMONSTRATING SOLAR HEAT FOR LIVESTOCK HOUSING IN VIRGINIA



Harold A. Hughes
Agricultural Engineering Department
College of Agriculture and Life Sciences
Virginia Polytechnic Institute and State University
Extension Division
Blacksburg, Virginia 24061

Sponsor: DOE/USDA
Contract/Grant No. 12-05-300-427
VPI & SU Project No. 231-11-110-002-333595-9

September 3, 1982

INTRODUCTION

The Virginia Solar Demonstration Project facilitated the construction of eight solar installations on farms in the Commonwealth. One system heated ventilation air for turkey poult brooding and one heated cleanup water for a dairy farm. The remaining units were all located on swine farms, and were used either to pre-heat ventilation air or heat water to warm the floor. One system also had the capability to cool summer ventilation air.

The project was funded by a grant from DOE/USDA which was supplemented by farmer investments in facilities and by contribution of faculty and staff time by the University (Virginia Polytechnic Institute and State University). The total project cost was approximately $200,000 of which $57,512, approximately 29 percent, was spent to construct the on-farm facilities.

This report discusses the goals and procedures which guided the overall project, the design of each individual system, the current status of the project, educational activities, and plans for future activities.

OVERALL PROJECT

The primary goal of the project was to increase the quantity and quality of information about solar heating systems that could be provided to Virginia Livestock farmers by establishing full-scale solar units on farms in the State. Toward that end, the following specific objectives were formulated.

Objectives

1. To increase the capability of extension workers to provide technical assistance to livestock producers considering a solar installation.
2. To demonstrate the technical feasibility of using solar energy to heat on-farm livestock shelters.
3. To evaluate the economics of solar energy for heating livestock shelters and to compare alternate systems for cost effectiveness.

4. To test the solar technology developed under an earlier DOE/USDA research program.
5. To develop effective solar heating system designs incorporating insulation, and other energy conservation features which minimize interference with normal operation of the facility.
6. Identify opportunities for widespread agricultural applications of solar energy and identify factors which serve as incentives for adoption of solar systems.

Procedure

The procedure followed in the development of the demonstration units was to: 1) identify a potential cooperator; 2) evaluate the potential for solar heating in his facility; 3) prepare a preliminary design; 4) submit a sub-contract; 5) submit design for technical review; 6) prepare final design drawings and specifications, 7) assist farmer to construct the unit, and 8) install instrumentation. These steps are discussed more fully in the following section.

Selection of Cooperators

Cooperators were selected from a list of available individuals which was developed through communication with local extension agents. It was attempted to obtain cooperators who were local or state leaders in their agricultural enterprize and who would be realistic in their expections and evaluations of the solar systems. In addition, criteria which were considered included: 1) previous experience with solar heating systems; 2) technical competence to operate and maintain the equipment; 3) suitability of the facility for the solar installation; 4) quantity of heat required; 5) seasonality of the heat requirement; 6) potential for multiple use of the solar system, and 7) availability of capital and other resources to be contributed by the cooperator. In addition, it was desired to have a geographical scattering of the systems in all parts of the state and to

have a variety of types of systems to facilitate educational efforts (i.e. farm visits) that were visualized.

In practice, these criteria were not all met. A relative large list of cooperators were considered and over 25 systems reached the stage of preliminary design. However, many of these efforts were abandoned because of inadequate operator capital. The situation was exacerbated by two consecutive years of severe drought which forced most of the potential cooperators to withdraw because of financial stresses. As a result, it was decided to build only eight systems, instead of the ten or eleven which were originally proposed. Also, the systems were grouped both geographically in the southeastern part of the state and by enterprize in the swine industry. However, the goal of having cooperators who were leading figures in their industry or community and who possessed the technical competence to deal with the equipment were clearly satisfied.

Goals for Systems

Each system design was handled as an individual case. Two units were supplied and installed by commercial solar equipment companies. The remainder were completely custom built designs. All designs were developed by or had approval of the Project Director.

Designs were developed to have minimal impact on the operation of the facility. For example, in several buildings, the systems pre-heated ventilation air but the conventional heating and ventilation systems were left in place and in operation. The only effect was to make the building and equipment perform as if it were in a warmer environment.

The designs were also developed to use component assemblies which were reliable, but were inexpensive as possible. All plans were clear and simple to facilitate construction and installation by personnel unfamiliar with solar

requirements. Examples of plans can be found in the fact sheets describing the systems in Appendix B.

In general, the goals discussed above were met. The demonstration systems experienced a few failures, discussed in later sections, but they generally functioned effectively and reliably with minimal changes.

Cooperator and Contracts Payments

After a preliminary design was prepared, the cooperator expressed his approval and commitment by signing and returning a sub-contract covering the relationship between him and the University. A standard contract form, prepared by the Legal Counsel for the University, was used. Appropriate notations were made to adopt the contract for each installation. Copies of the signed contract were maintained by the Cooperator and the University. A sample contract is attached (Appendix A). Each cooperator was encouraged to have the contract reviewed by his personal Lawyer before signing.

Under the terms of the contracts with the University, the cooperators were responsible for construction and installation of the solar equipment. However, in practice, considerable assistance and supervision was provided by the University personnel.

After the system was completely installed and had passed a preliminary operating check, the cooperator submitted a statement of his total expenses. An example of a billing statement is attached (Appendix C). The billing was checked for accuracy and the University share was calculated. A check was then issued to the cooperator to reimburse him for the share of construction costs covered by the University.

There was no further financial support provided except in cases where a design change was made. The cost of such modifications were covered by the same 50/50 University/Cooperator split as was used to cover the initial system construction costs.

Instrumentation

A variety of instrumentation was selected, depending on the monitoring plan for each installation. In two cases BTU meters and thermometers were installed as an integral part of the system. The meters were read and recorded by the cooperator who then forwarded the data to the University for analysis.

The remaining systems were monitored through the use of moveable recorders. Considerable difficulty was experienced with the data loggers. Consequently, little "hard" information has been collected on most of the systems. The section discussing the individual systems will present a further discussion of instrumentation and the data collection and evaluation scheme.*

INDIVIDUAL SYSTEMS

A total of eight systems were designed and built under the project. Locations of the systems, by county, are shown in Figure 1.

Table 1 is a summary of the characteristics of the systems, giving location, cost, collector size and other pertinent statistics. In addition, a fact sheet describing each system is attached (Appendix B).

Several conclusions can be reached from an examination of the information in Table 1. These are summarized and discussed briefly in the following section.

1. The initial cost of the two commercial systems, on a per square foot of collector basis, was more than twice as high for the two commercial

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*The final evaluation had been scheduled for the 1982-83 heating season on the assumption that the project would terminate September 30, 1983. This plan was precluded when the termination date was advanced to September 30, 1982. However, the systems will be monitored to the greatest extent possible during the 1982-83 season using support from other sources. The information gained will be made available through the usual scientific and extension channels.



Figure 1: Location of solar heated livestock systems in Virginia, by county.

Tabel 1: Characteristics and Costs of Solar Demonstration Units.

Cooperator	Location (County)	Use	Collector Area (sq. ft.)	Storage	System Cost ($)	Unit Cost ($/sq. ft. of collector)
Torrence	Appomattox	Dairy cleanup water*	65	55 gal. H_2O	2,800	43.08
Wampler	Rockingham	Turkey brooding	640	12,000 gal. H_2O	19,066	29.79
Kitchen	Southampton	Swine heated floor*	60	80 gal. H_2O	3-700	61.67
Smith	Henry	Swine heated floor	256	280 gal. H_2O	5,168	20.19
Whitley	Southampton	Swine heated floor	384	1100 gal. H_2O	6,794	17.69
Davis	Accomac	Swine solar storage wall	392	521 cu.ft. concrete	9,246	23.58
Bryan	Buckingham	Swine solar storage wall	368	489 cu.ft. concrete	2,927	7.95
Robinson	Greensville	Swine solar storage wall	288	383 cu.ft. concrete	7,811	27.12

*Commercial units installed by supplier. All other systems built "from scratch" under direction of cooperators.

units as for the six home-built units. The commercial systems cost an average of $52.38 per sq. ft. while the home built units averaged $21.05 per sq. ft.

2. A comparison of the three solar heated floor systems and the three solar storage walls showed that the heated floor units were more expensive on the average to install ($33.18 per sq. ft. vs. $19.55 per sq. ft.). However, if the Kitchen and Bryan systems are not considered, the differences is much smaller.
3. A wide range of costs can be expected, depending on scale of the system and the complexity. For example, the unit cost of the Kitchen system was more than twice as high as the Smith and Whitley systems, primarily because the costs of pumps, controls and similar equipment was "spread" over less collector area. The effect of complexity is shown by a comparison between the Davis, Bryan and Robinson systems which were all variations of the solar storage wall. The Davis wall incorporated cooling capability, requiring extra fans, mechanical louvers, controls, etc. The Robinson wall was built across the end of a building oriented N-S. The Bryan unit, on the other hand, was an ideal site for the wall, requiring little effort to install. As a consequence, the unit cost of the Bryan system was 33.7 percent and 29.3 percent of the Davis and Robinson walls, respectively. Obviously, careful design and construction have the potential to yield substantial cost savings.

INSTRUMENTATION AND EVALUATION

As stated above, the major evaluation effort was planned for the 1982-83 heating season. The equipment for the major part of the effort was a system developed and produced at Kansas State University. The system consists of the following components: 1) three portable data loggers; 2) a read-out unit; and

3) a micro-computer (Figure 2). The data loggers are installed at a particular farm and connected to sensors, including thermocouples, air velocity transducers, static pressure transducers and other devices which produce a voltage related to some physical variable. The sensors are scanned periodically and the results are averaged over a pre-set period of time. Both the scanning interval and the interval between averaging are programmable through switch settings on the micro-computer board which controls the data logger. After averaging, the data is recorded onto a standard cassette tape, along with date, time and identification of the site or the machine.

Periodically, the cassette tape can be replaced and the tape containing data sent to the University to be read. The tape unit is a standard cassette recorder, so the tape changing is usually done by the cooperator.

The tape reader is a unit similar to the data loggers, but without the extra equipment to scan and read the sensor voltages. The reader decodes the information from the tape, performs preliminary accuracy checks and sends the results through an RS-232 interface to a TRS-80* micro-computer. The TRS-80 controls the operation of the tape reader, periodically suspending data transmission to record the information on a diskette (i.e. floppy disk) and/or to print a hard copy of the data.

The data can then be retrieved from the diskette and sent to the University mainframe computer for further analysis or the analysis and preparation of graphs, charts, and tables can be done on the small machine, depending on the requirements of the particular situation.

Some difficulty was experienced in getting the data system to operate. As a consequence, little information has been gathered to date to characterize the

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*TRS-80 is a trade mark of the Tandy Corporation.

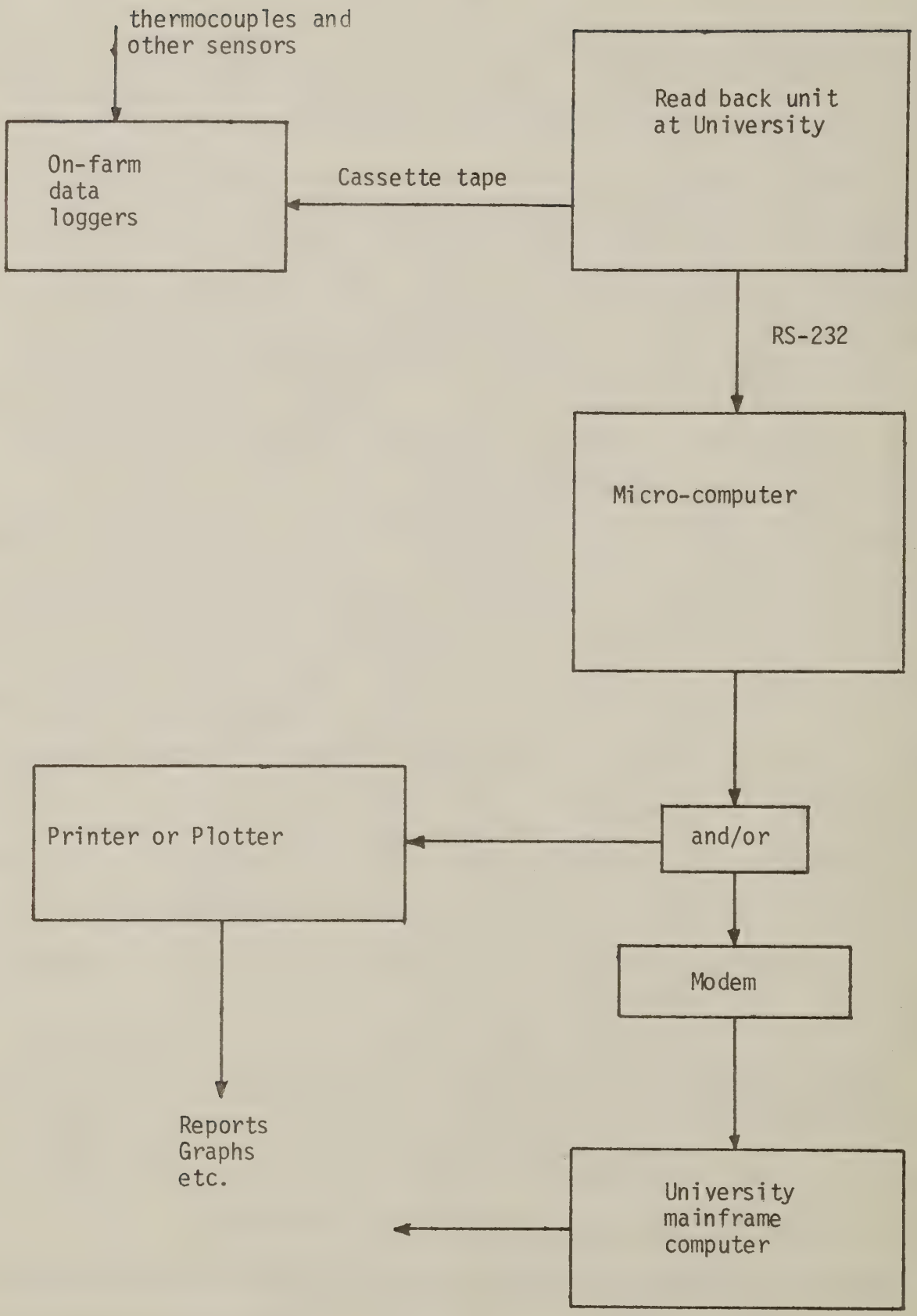


Figure 2: Portable computer based instrumentation system.

solar systems on the swine buildings during the heating season. However, the units are now operating satisfactorily and the planned evaluations will be carried out as rapidly as available resources permit. Funding has been requested from state agencies to support the evaluation work.

Torrence System Evaluation

The Torrence system, which was designed to supply part of the heat for clean-up water in the milking center was monitored through the use of integral instrumentation. Data was recorded twice daily by the cooperator and mailed to the University for evaluation.

The results are included with the fact sheet (ME-124, Appendix B). Figure 3 and Figure 4 present a summary of the information for a 1981-82 test period.

The average monthly values of electric energy, solar energy, and total energy are shown in Figure 3. The percentage of energy supplied by the solar system is shown in Figure 4. The times of various changes that were made in the system are also noted. Several changes were made to increase the "yield" of solar energy, including extra tank insulation, a heat loop to prevent heat loss from the final tank to the solar tank and a change in collector angle. As a result, the solar system consistently produces over 10 KWH per day. This heat yield is relatively constant (Figure 3) and the electric system provides the remaining energy that is needed.

During August and September of 1981, the cooperator participated in a study of low temperature cleaning of his milk handling equipment using a special detergent and 110°F water. During those two months, total energy requirements and the use of electricity both dropped sharply (Figure 3). During this period, the percentage of heat supplied by the solar system rose to a peak of 96% (Appendix B). However, the absolute quantity of heat remained around 10 KWH.

Date		Elect	Solar	Total	% Solar
'80	J	13	7	20	36
	A	13	8	21	38
	S	16	9	25	36
	O	17	9	26	35
	N	(17)	(8.5)	(25.5)	(33.5)
	D	17	8	25	32
'81	J	23	10	33	30
	F	21	11	32	33
	M	18	11	29	38
	A	17	10	27	37
	M	15	10	25	40
	J	11	10	21	48
	J	10	10	20	50
	A	3	10	13	77
	S	6	10	16	63

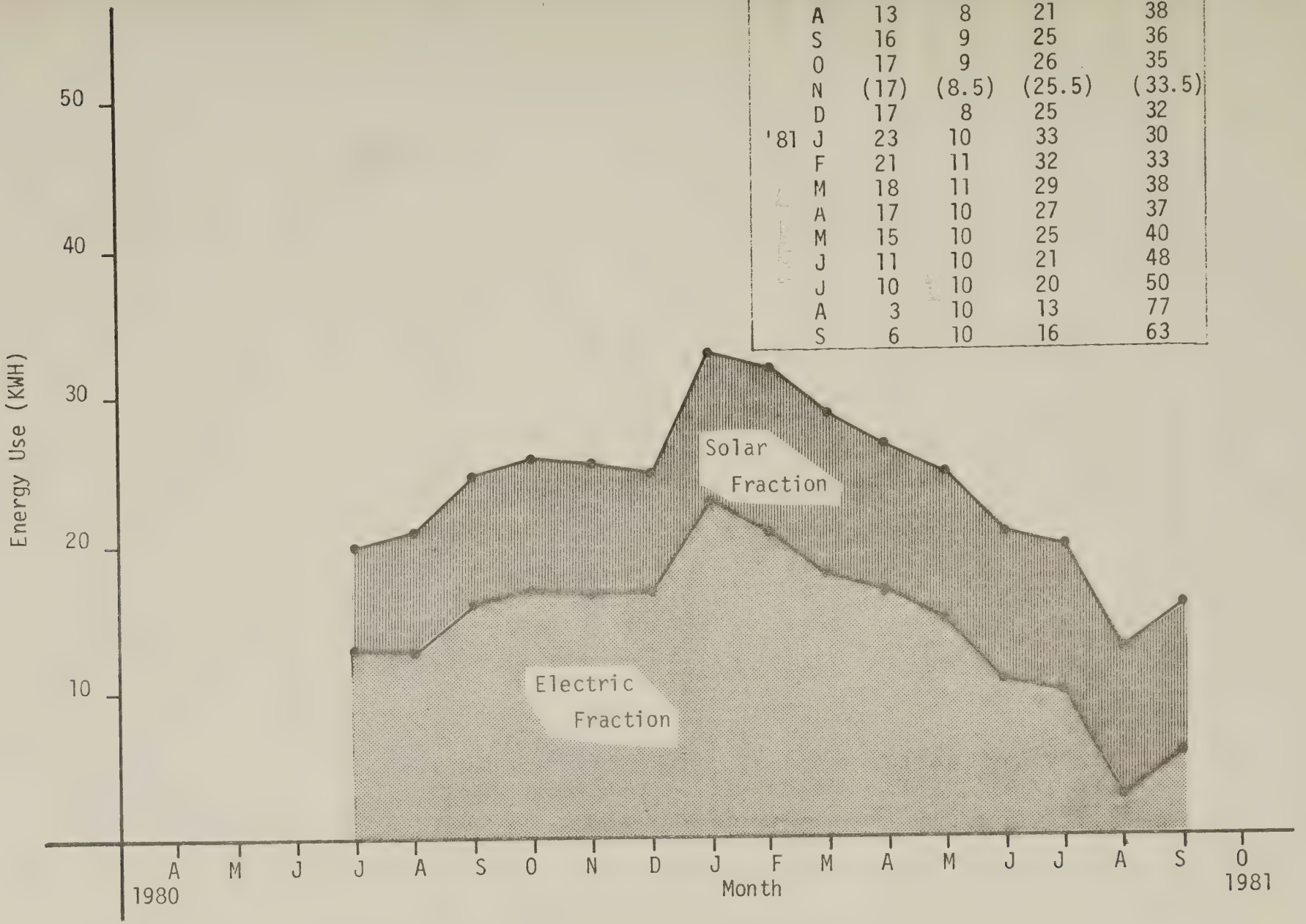


Figure 3: Energy supplied by electrical system and solar system.

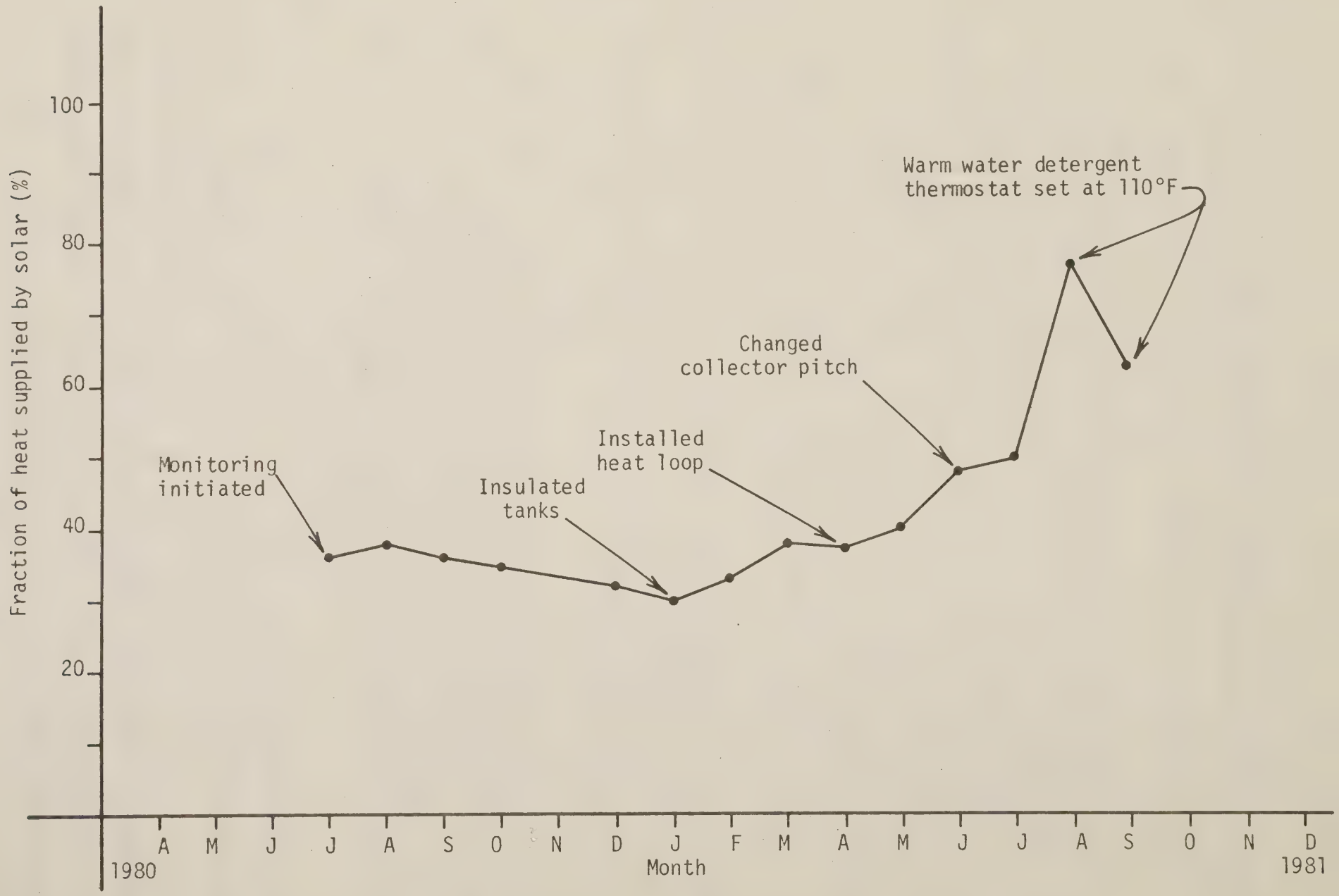


Figure 4: Average percent of energy supplied by the solar system.

EDUCATIONAL ACTIVITIES

Much of the educational activity is planned to follow the complete evaluation of the performance of the various systems. However, several activities have been undertaken during the period that the project was active. These are outlined in the following section.

1. Fact sheets were prepared describing the design and construction of each system (Appendix B). These were distributed to producers, builders and others who could use the information.
2. The systems and the overall project have been described and discussed in numerous news articles, TV appearances, and radio tapes.
3. The Torrence system was a prominent part of the 1982 Farm Management Tour. A copy of a news article prepared to publicize the tour is included in Appendix D.
4. A display, showing system designs and photographs of the various systems has been prepared and shown at energy fairs, the Virginia State Fair (Atlantic Rural Exposition), utility offices and other appropriate places.
5. Plans of the systems have been distributed on request.
6. The project has led to other work, such as design and construction of a "bread box" solar water heater for application where capitol is limited and the design and construction of a solar greenhouse at the West Central 4-H Educational Center at Smith Mountain Lake.
7. A slide tape presentation showing ways to save money and energy for domestic water heating has been prepared and will be used in an emphasis program during 1983.
8. Various VIP's, including both candidates for Governor of Virginia, and the Agricultural Attache from the German Democratic Republic have visited the units.

Future Educational Activities

Future activities will continue the present work, but will use more economic and operational information to emphasize the requirement for low cost, but efficient, effective and reliable systems. A slide tape and a video-tape will also be prepared and used in extension educational programs and for resident instruction at the University.

CONCLUSIONS

Since the evaluations have not been completed, the following set of conclusions is not as complete as had been intended. However, by drawing on the information gained during design, construction, de-bugging and operation of the systems, along with such information as is available from other sources, the following conclusions were reached.*

1. Solar heating systems can be constructed that function effectively and reliably on livestock farms.
2. Home built systems tend to be lower in initial cost than commercial units.
3. Depending on the design and materials used, a wide range of initial system costs can result. No information exists to test the strength of the correllation between initial cost and performance.
4. Heated floor units using water from a solar system are inherently inefficient because the auxilliary heating system maintains the operating fluid at a relatively high temperature (above 110°F). Such systems may be more effective if a water-to-water heat pump is included between the solar system storage tank and the floor heating circuit. More testing is needed.

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*Additional, more specific conclusions will be issued later.

5. Solar storage walls can be built at a relatively low cost. They require essentially no change in normal building operation.
6. The economics of solar heat for livestock shelters are not attractive at the current time. Payback periods of 10 to 20 years can be expected unless extreme care is used to control the initial cost of the installation.

APPENDIX A

Sample sub-contract

VIRGINIA'S LAND-GRANT UNIVERSIT

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSIT

Blacksburg, Virginia 240

OFFICE OF THE GENERAL COUNSEL

December 4, 1979

To Whom It May Concern:

As General Counsel for Virginia Polytechnic Institute and State University, I have examined a Contract to be offered to farm-owners whose solar heating projects will be subsidized under USDA/SEA-Extension Cooperative Agreement and Virginia Polytechnic Institute and State University.

This contract is approved as to form and substance.

Lee B. Liggett

LBL:gsk

Subcontract

between

and

Virginia Polytechnic Institute and State University

Purpose of Agreement

Virginia Polytechnic Institute and State University (Virginia Tech) is the recipient of Cooperative Agreement Number 12-05-300-427 from the Science and Education Administration - Extension, U. S. Department of Agriculture, for a project entitled, "Demonstrating Solar Heating of Livestock Housing in Virginia".

A major feature of this project is that Virginia Tech will work with certain farmowners to demonstrate the technical feasibility of using solar energy for heating on-farm livestock shelters. This will involve cooperating with the farmowners in developing a solar heating system appropriate to his needs, reimbursing the farmowner for certain costs, and evaluating the performance of the system for a certain period after its installation.

This Reimbursement Agreement defines the conditions under which Virginia Tech will cooperate with

(the farmowner), and the terms of Virginia Tech's reimbursement to the farmer, to develop, install, operate and evaluate a solar heating system for livestock shelters on the farmowner's property.

Period of Agreement

This agreement will become effective on the date of the last signature. It will remain in effect through September 30, 1980. Virginia Tech's Cooperative Agreement with USDA terminates annually on September 30, but may be renewed annually by USDA. Therefore, Virginia Tech reserves the right unilatterally to extend this agreement annually to the following September 30, for a period of three years, unless the parties have exercised their rights to terminate this agreement.

Virginia Tech Agrees:

1) To assist the farmer in designing, selecting, and/or planning a solar heating system for

2) To reimburse the farmer % of the costs of such equipment, not to exceed $. (If these figures are not known at the time this agreement is signed, insert "unknown". A memorandum signed for

Virginia Tech and for the farmowner shall be appended to the agreement and become a part of it to define these figures). Title to this equipment will vest in the farmowner upon aquisition.

3) To provide personnel, equipment and services necessary to evaluate the performance of the solar heating equipment. None of the equipment used for this purpose shall become the property of the farmowner.

4) To make an economic evaluation of the solar heating installation.

The Farmowner Agrees:

1) To install and operate for a period of 3 years, a solar heating system for

2) To submit to Virginia Tech a design and budget for the solar heating equipment. These must be approved by Virginia Tech prior to procurement of the equipment in order that the farmowner may be reimbursed part of the cost. Any change in the approved design or budget must be mutually agreed to and signed by both parties' representatives. Virginia Tech shall be the sole judge of the allowability of reimbursement either in excess of the budgeted amount or for equipment not previously approved.

3) To retain for 3 years and make available to Virginia Tech upon request invoices and other records to substantiate the procurement cost of the solar heating equipment.

4) To allow Virginia Tech access to the property, location and solar heating equipment, and to maintain this area and equipment in a manner to prevent safety hazards to Virginia Tech personnel or other persons.

5) To provide Virginia Tech information, such as prior expenses and animal performance, which will assist in economic evaluation.

6) To allow, at reasonable times and with prior notice from Virginia Tech, groups of visitors access to the property, location and solar heating equipment for demonstrations, tours and workshops.

7) To allow Virginia Tech and the U. S. Government unlimited rights to publish information about the installation, including data which may be provided by the farmowner.

8) To comply with the provisions of Executive Order No. 11246, dated September 24, 1965, Section 202, Para. (1) through (7), and such rules for implementation as shall be made by appropriate Federal authority. It is noted that the principle effect of Executive Order 11246 is that contractors and subcontractors of the Federal Government "will not discriminate against any employee or applicant for employment because of race, color, religion, sex, or national origin [and] will take affirmative action to ensure [such non-discrimination]". It is further noted that Revised Order No. 4 (41 CFR 60-2)

applies the requirements to have a written affirmative action compliance program to any "subcontractor with 50 or more employees and a contract of $50,000".

Virginia Tech and the Farmowner Mutually Agree:

1) That Virginia Tech's representative to the farmowner shall be and that the farmowner's representative to Virginia Tech shall be ,

2) That payment to the farmowner shall be made by Commonwealth of Virginia check on the following schedule, and on presentation of a claim for this payme supported by appropriate documentation of the farmowner's expenses.

(Enter mutually agreed schedule. If not known at the time this agreement is signed, insert "unknown". A memorandum signed for Virginia Tech and for the farmowner shall be appended to the agreement and become a part of it to define these figures.)

3) That Virginia Tech will use its best professional efforts in any design assistance it gives, but that it offers no guarantee regarding the performance of any solar heating system and will accept no liability in regard to such system, its effects, or its technical and/or economic feasibility.

4) That it is the intent of both parties that the solar heating equipment shall be in operation for a period of .
Should the farmowner exercise his right to terminate the agreement, Virginia Tech accepts no responsibility or liability for removing the solar heating equipment or for restoring any of the farmowner's property to its former condition.

5) That Virginia Tech shall be solely responsible where found liable, to the extent covered by insurance, for the payment of any and all claims for loss, personal injury, death, property damage, or otherwise, arising out of any act or omission of its employees or agents in connection with this subcontract, except in the matters listed above wherein Virginia Tech specifically rejects assumption of any liability.

6) That this agreement may be terminated at any time by either party upon delivery to the other party of written notice 30 days in advance of the intend date of termination.

7) That no member of or delegate to Congress shall be admitted to any share or part of this agreement, or to any benefit that may arise therefrom; but this provision shall not be construed to extend to this agreement if made with a corporation for its general benefit.

8) That this agreement constitutes the entire agreement between the parties, and that it shall be modified only in writing, executed for both parties.

Signed for Virginia Tech

Name

Date

Signed for Farmowner

Name

Date

APPENDIX B

Fact Sheets

Agricultural Engineering

ENERGY MANAGEMENT SERIES

February 10, 1981 ME-124

SOLAR DEMONSTRATION NO. 1
Torrence Dairy Farm
(Phase 1)

H. A. Hughes D. W. Platt

Agricultural Engineering Department

This publication describes a demonstration solar system which has been installed on the Torrence dairy farm in Southside Virginia. The system is designed to provide a portion of the energy needed to heat water used for washing udders and cleaning equipment in the milking center of a dairy farm. Development of the system was supported by Mr. Torrence, along with the United States Department of Agriculture, the United States Department of Energy, and the Virginia Tech Extension Division.

THE FARM

The Torrence farm is located near Appomattox, Virginia. Mr. Torrence milks about 55 cows, producing most of the needed feed. He is also a tobacco producer. A conventional milking system, using pipeline milkers and bulk handling is used. Hot water, about 165°F, is used to clean equipment after each milking. Cooler water, approximately 120°F, is used for preparing calf feed.

PROJECT OBJECTIVES

The following objectives governed the design and construction of the system.

*Use solar energy to heat water used for clean-up and calf feeding.

*Evaluate the economics of solar heat for a dairy farm in order to compare solar to other alternate sources of heat.

*Compare a two tank system to the single tank system used in Demonstration No. 3.

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SYSTEM DESCRIPTION

The unit installed on the Torrence farm is a standard domestic solar water heater with extra collector panels. Collector area is approximately 65 square feet. Water circulates to the collectors from a pre-heat tank. The pre-heat tank is a standard water heater without the heating elements. Water is drawn, as it is used, from the pre-heat tank to a second water heater which is equipped with heater elements. The second tank raises the water temperature to 165°F required for cleaning equipment. Water for other uses can be drawn from either tank, depending on the temperature required. A draindown freeze protection system is used.

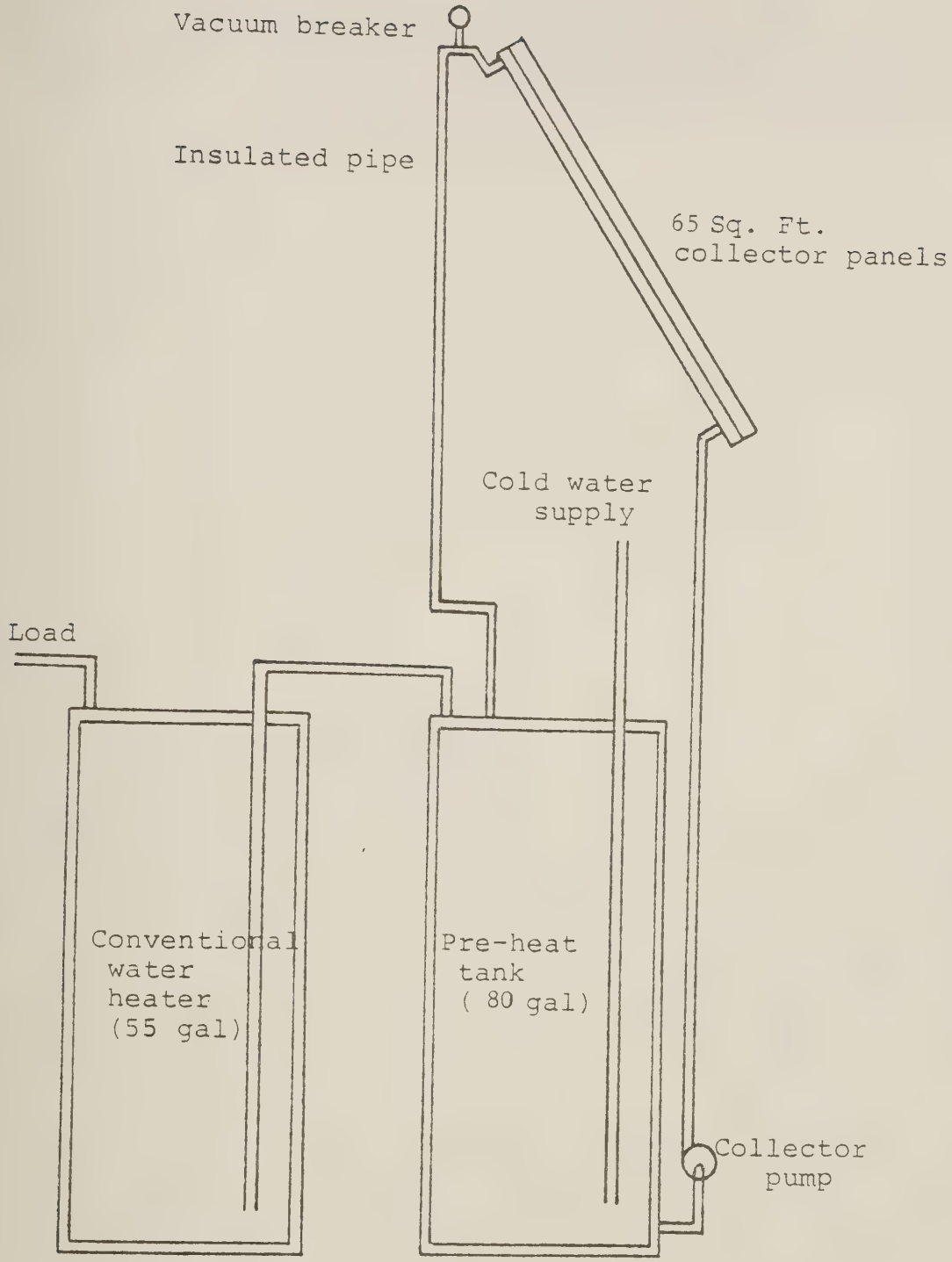
PERFORMANCE

The system, completely installed and in operation, cost $2,800. It has functioned well to date. Maintenance is simple. One panel was broken by a rock thrown up from a piece of machinery. It was a simple matter to remove the damaged panel and replace it with a new unit.

At present, the system is supplying about 38 percent of the needed heat. This is less than the preliminary calculations predicted, so the entire system is being re-tested to determine if; 1) water use is greater than expected, 2) heat is being lost from the system at some point or 3) the instrumentation is malfunctioning.

COMMENTARY

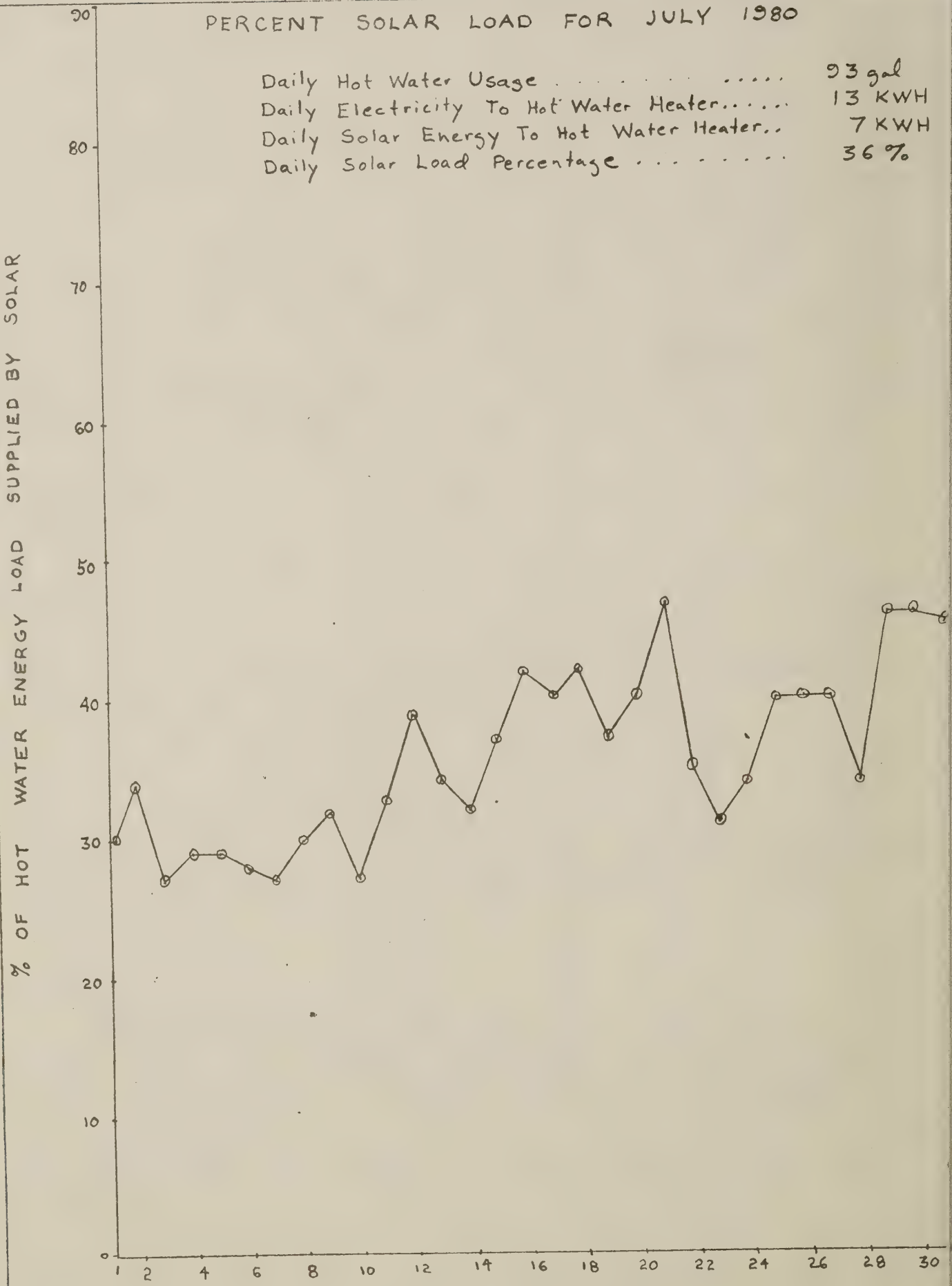
No design changes are being contemplated at this time. However, solar heating of dairy center water is not being recommended, pending the completion of the demonstration and the evaluation of the data from this project and equivalent systems using equipment for scavenging heat from the bulk tank compressor.


Vacuum breaker
Insulated pipe
65 Sq. Ft.
collector panels
Cold water
supply
Load
Conventional
water
heater
(55 gal)
Pre-heat
tank
(80 gal)
Collector
pump

Dennis Torrence

PERCENT SOLAR LOAD FOR JULY 1980

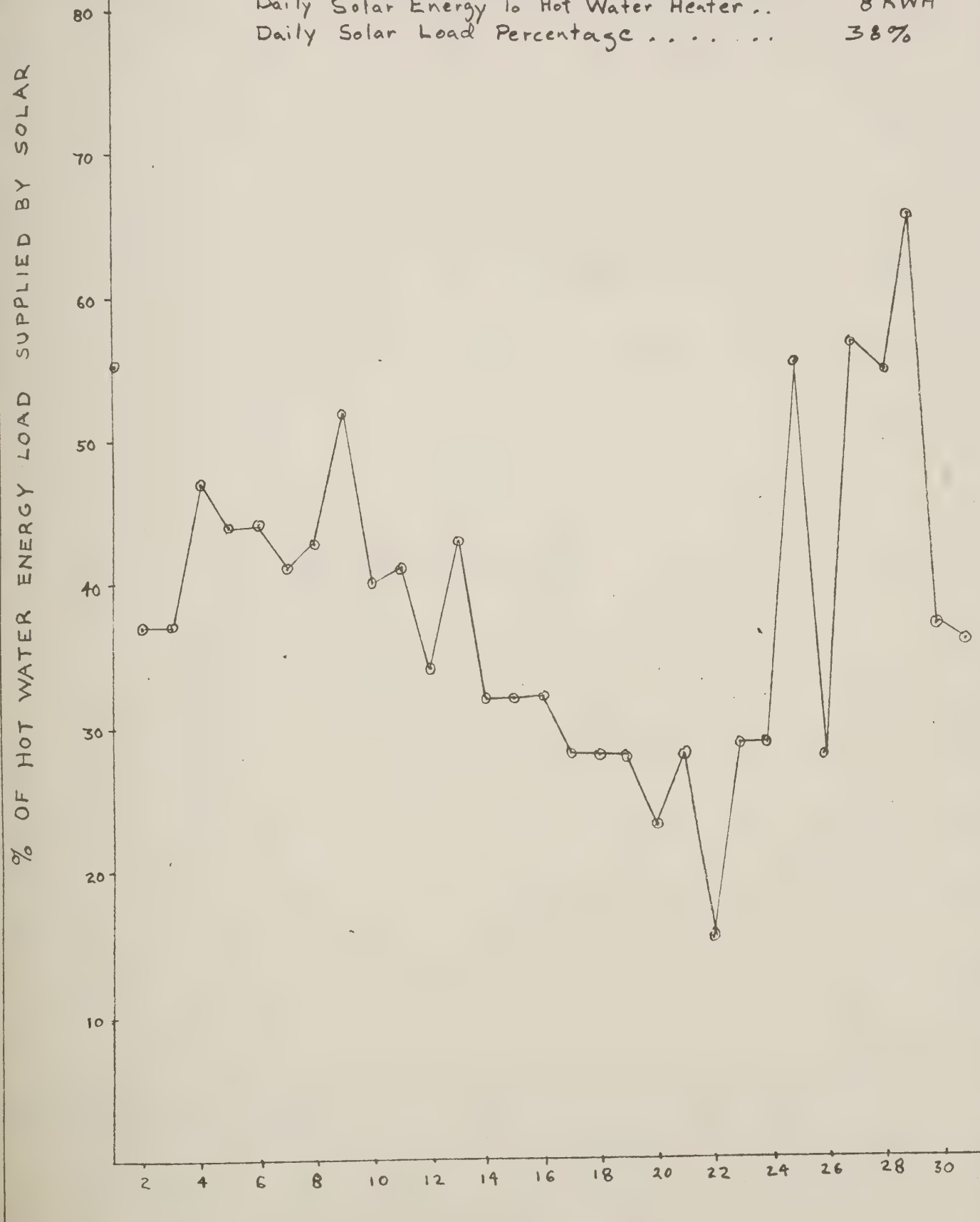
Daily Hot Water Usage	93 gal
Daily Electricity To Hot Water Heater.	13 KWH
Daily Solar Energy To Hot Water Heater. .	7 KWH
Daily Solar Load Percentage	36 %



Dennis Torrence

PERCENT SOLAR LOAD FOR AUGUST 1980

Daily Hot Water Usage	94 gal
Daily Electricity To Hot Water Heater	13 KWH
Daily Solar Energy To Hot Water Heater	8 KWH
Daily Solar Load Percentage	38%

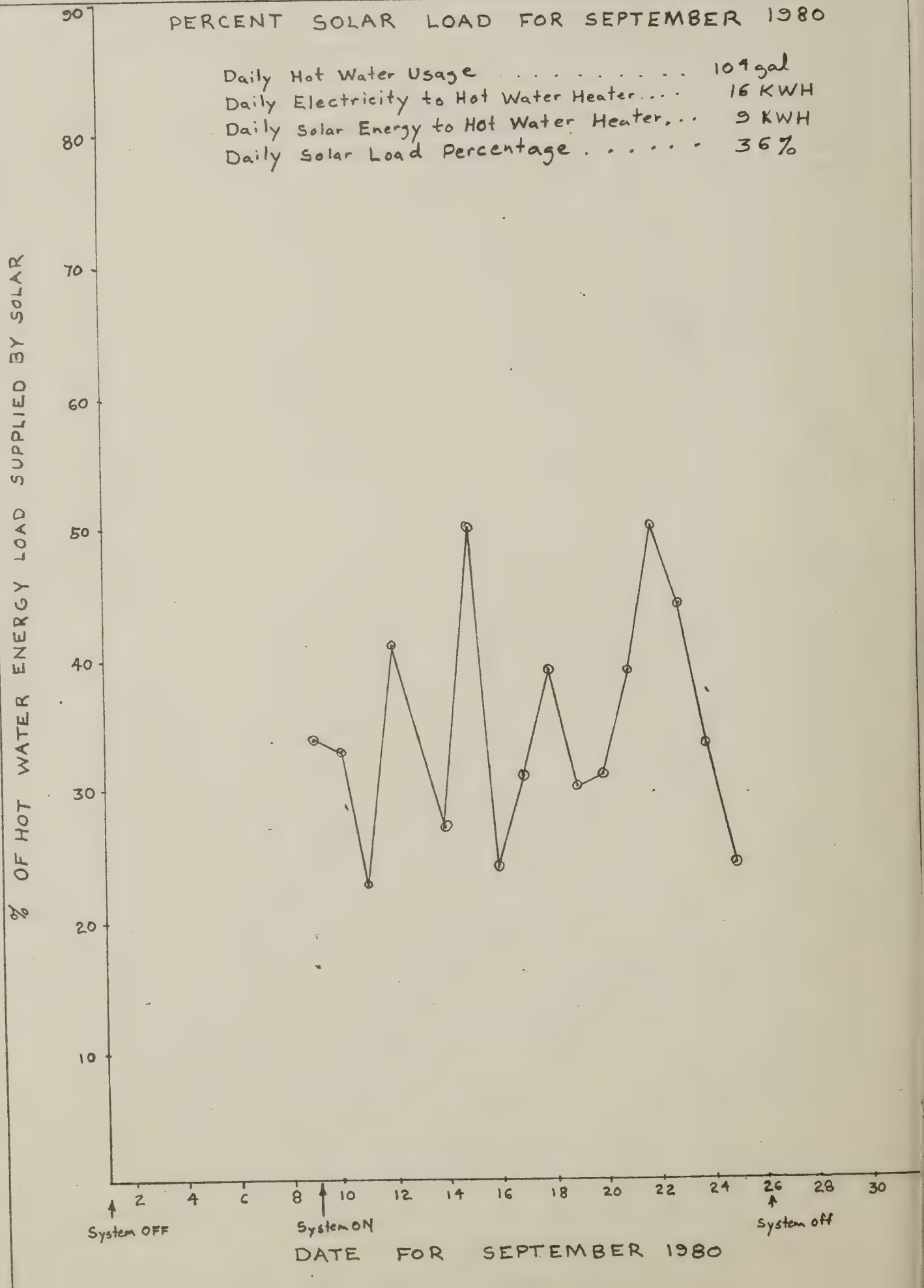


42-382 100 SHEETS 5 SQUARE
42-389 200 SHEETS 5 SQUARE
NATIONAL

Dennis Torrence

PERCENT SOLAR LOAD FOR SEPTEMBER 1980

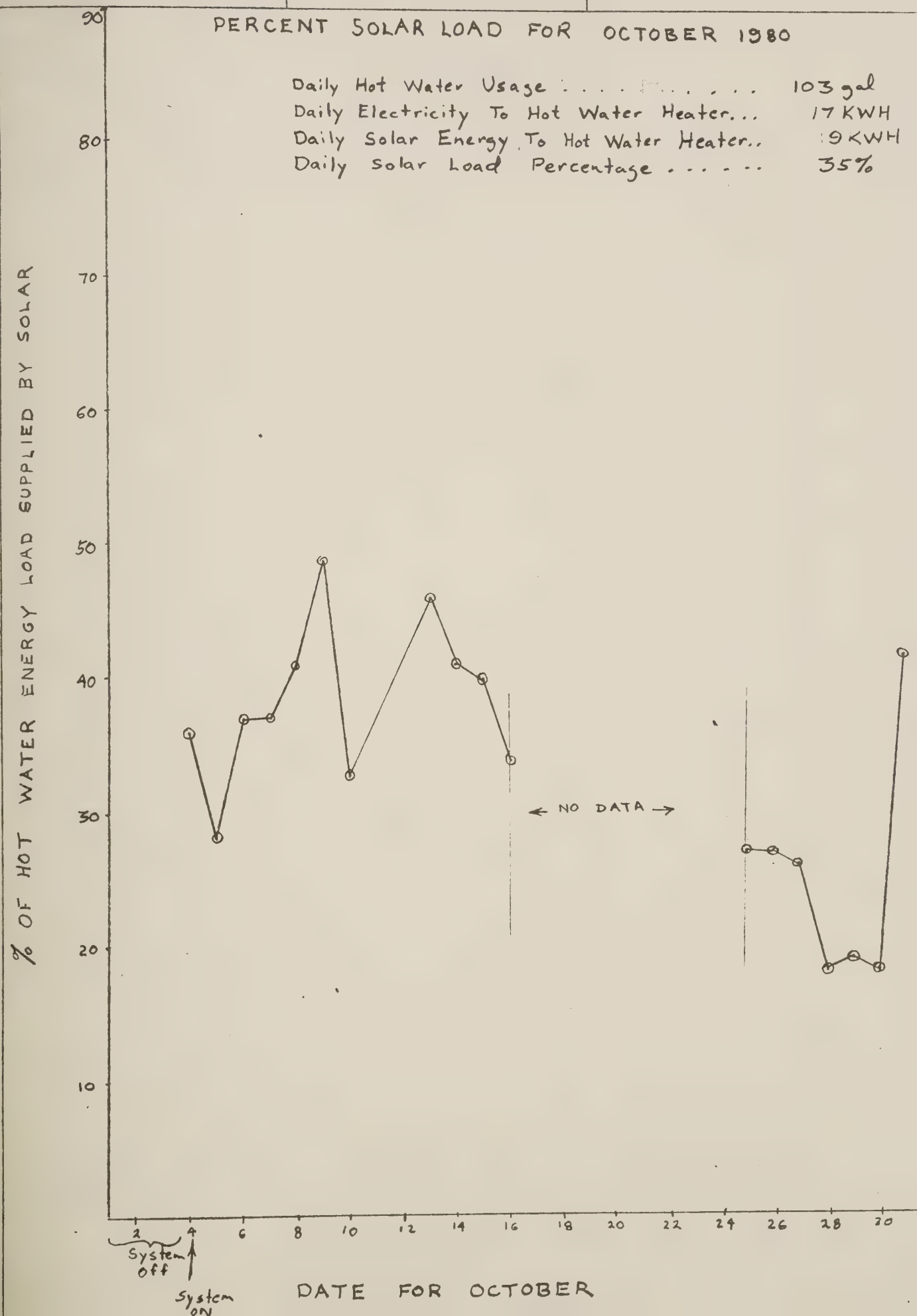
Daily Hot Water Usage	104 gal
Daily Electricity to Hot Water Heater. . . .	16 KWH
Daily Solar Energy to Hot Water Heater. . .	9 KWH
Daily Solar Load Percentage	36%



Dennis Torrence

PERCENT SOLAR LOAD FOR OCTOBER 1980

Daily Hot Water Usage	103 gal
Daily Electricity To Hot Water Heater...	17 KWH
Daily Solar Energy To Hot Water Heater..	9 KWH
Daily Solar Load Percentage	35%

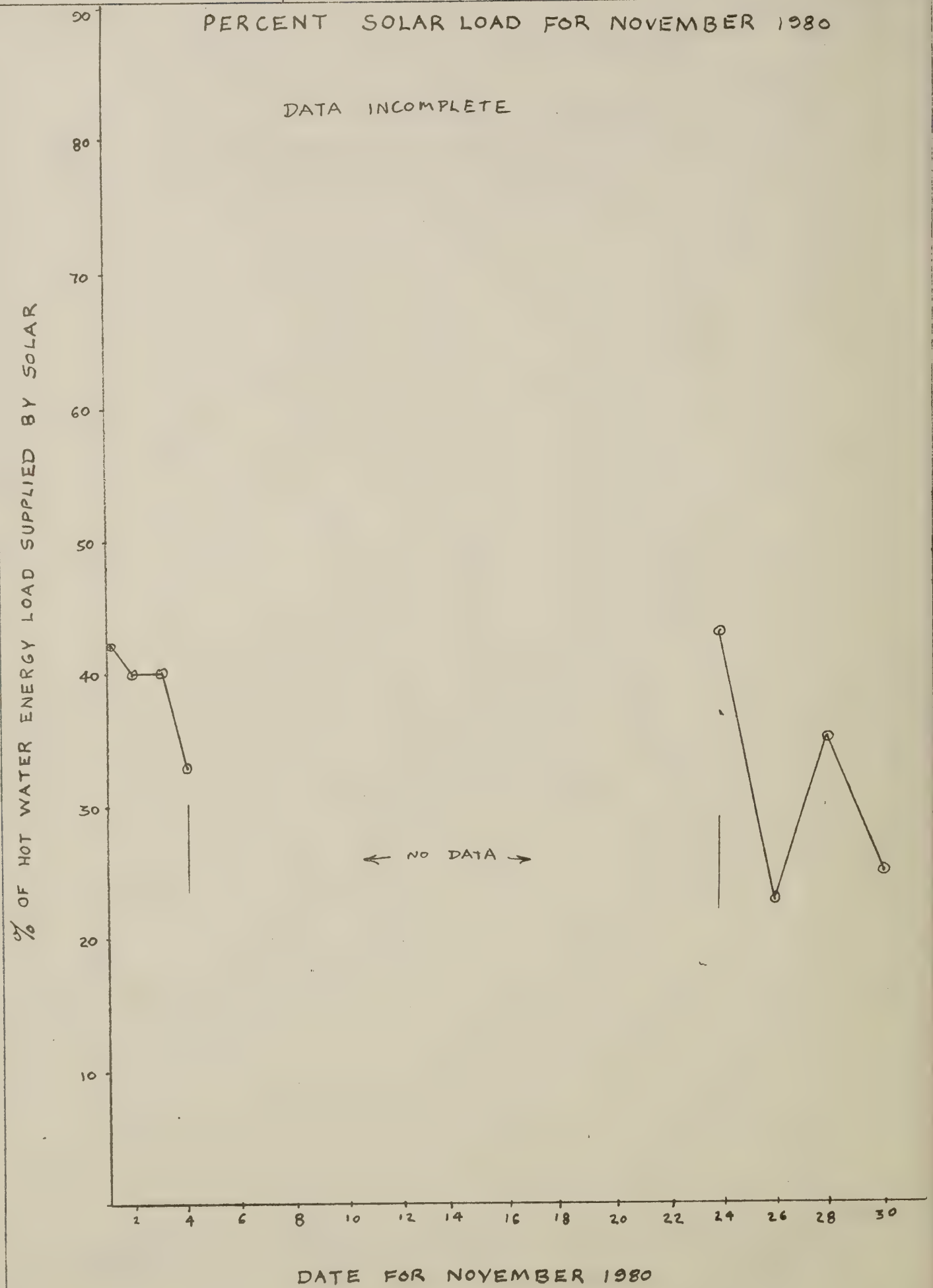


42-382 100 SHEETS 5 SQUARE
42-389 200 SHEETS 5 SQUARE
NATIONAL

Dennis Torrence

PERCENT SOLAR LOAD FOR NOVEMBER 1980

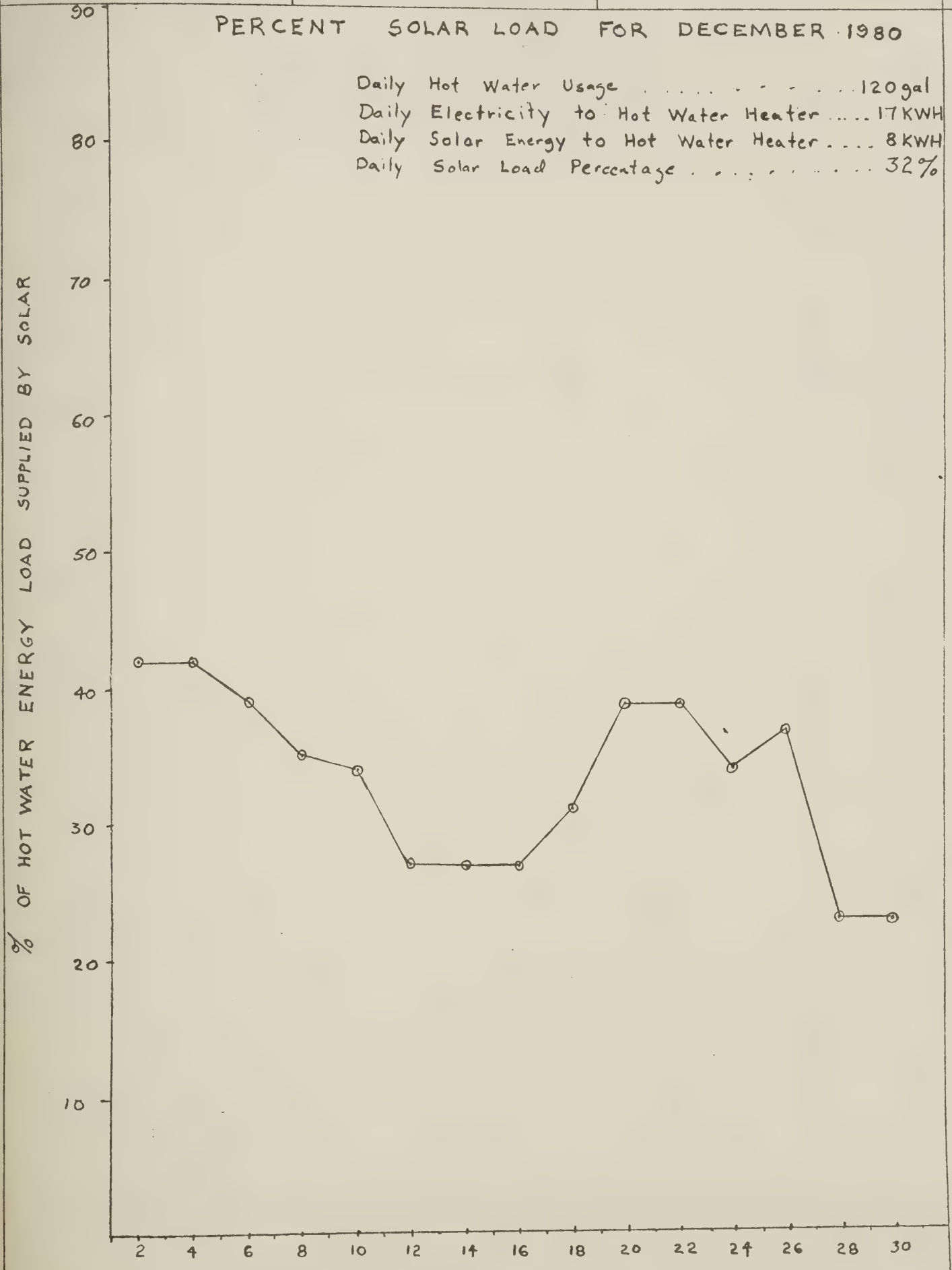
DATA INCOMPLETE



Dennis Torrence

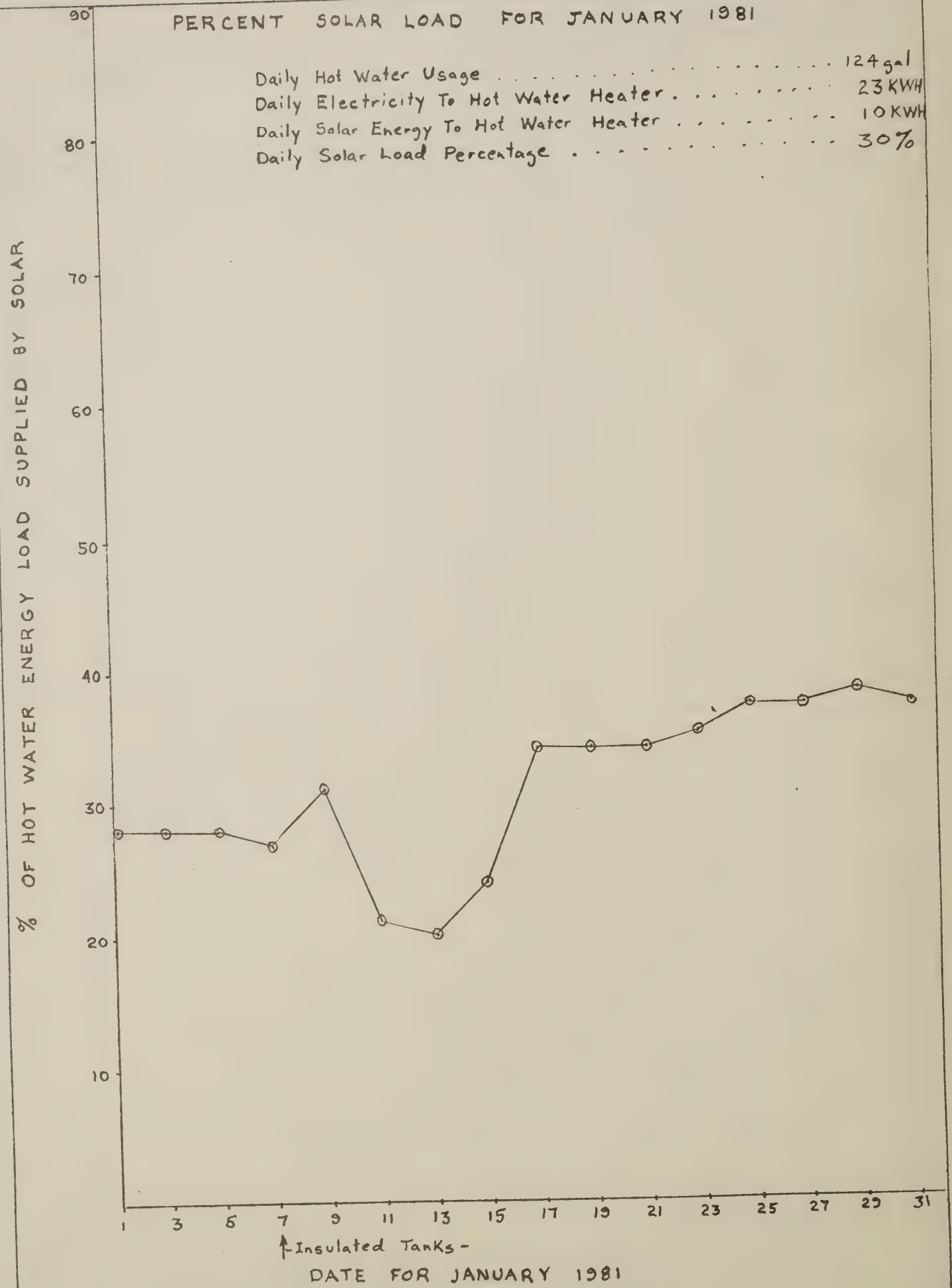
PERCENT SOLAR LOAD FOR DECEMBER 1980

Daily Hot Water Usage . . . . . 120 gal
Daily Electricity to Hot Water Heater . . . . 17 KWH
Daily Solar Energy to Hot Water Heater . . . . 8 KWH
Daily Solar Load Percentage 32%



PERCENT SOLAR LOAD FOR JANUARY 1981

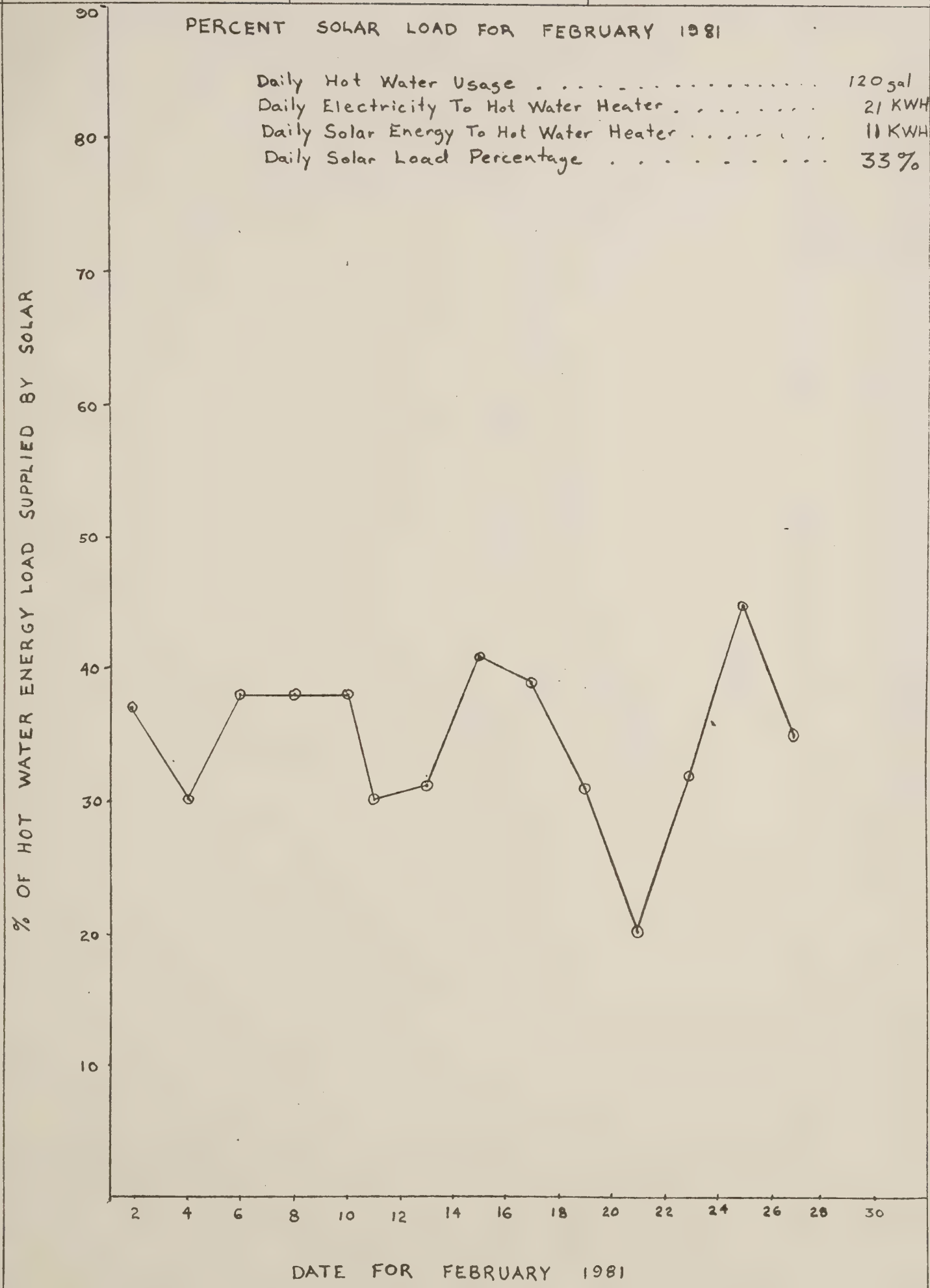
Daily Hot Water Usage . . . . . 124 gal
Daily Electricity To Hot Water Heater . . . . . 23 KWH
Daily Solar Energy To Hot Water Heater . . . . . 10 KWH
Daily Solar Load Percentage 30%



Dennis Torrence

PERCENT SOLAR LOAD FOR FEBRUARY 1981

Daily Hot Water Usage	120 gal
Daily Electricity To Hot Water Heater	21 KWH
Daily Solar Energy To Hot Water Heater	11 KWH
Daily Solar Load Percentage	33%

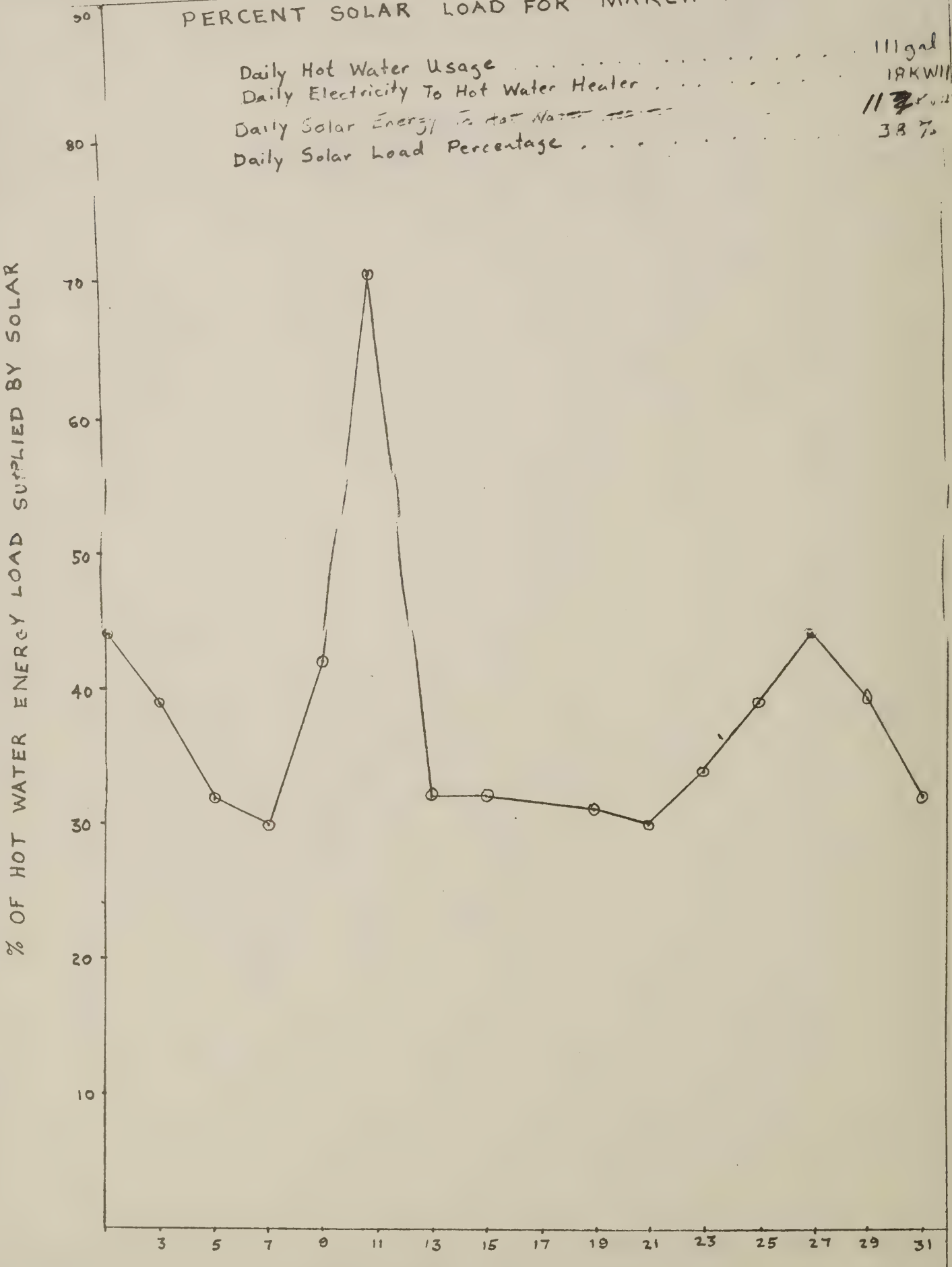


42-381 50 SHEETS 5 SQUARE
42-382 100 SHEETS 5 SQUARE
42-389 200 SHEETS 5 SQUARE
NATIONAL

Dennis Torrence

PERCENT SOLAR LOAD FOR MARCH 1981

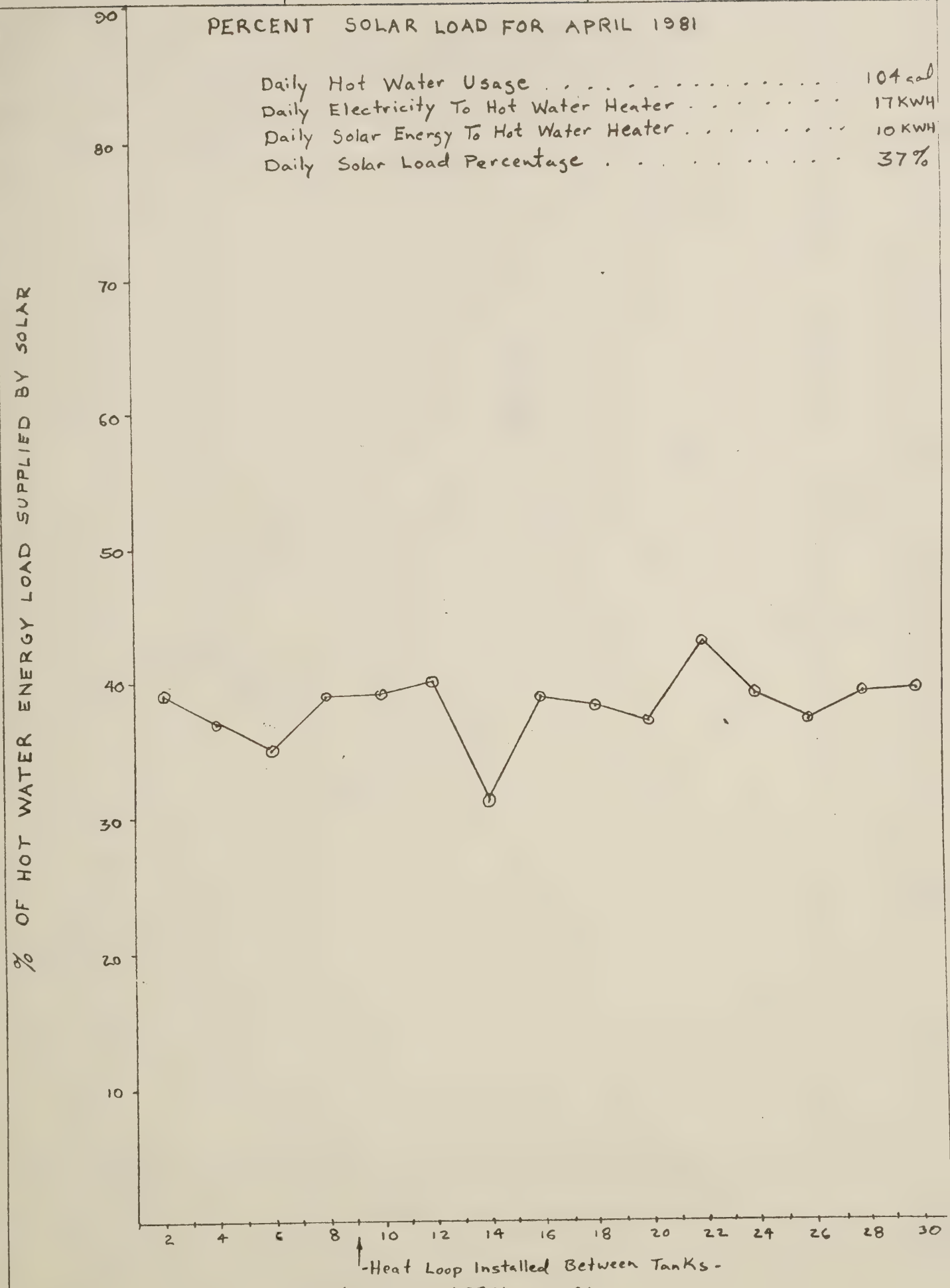
Daily Hot Water Usage . . . . . 111 gal
Daily Electricity To Hot Water Heater . . . . . 18 KWH
Daily Solar Energy To Hot Water Heater . . . . . 11 ~~3~~ KWH
Daily Solar Load Percentage . . . . . 38 %



Dennis Torrence

PERCENT SOLAR LOAD FOR APRIL 1981

Daily Hot Water Usage	104 gal
Daily Electricity To Hot Water Heater	17 KWH
Daily Solar Energy To Hot Water Heater	10 KWH
Daily Solar Load Percentage	37%

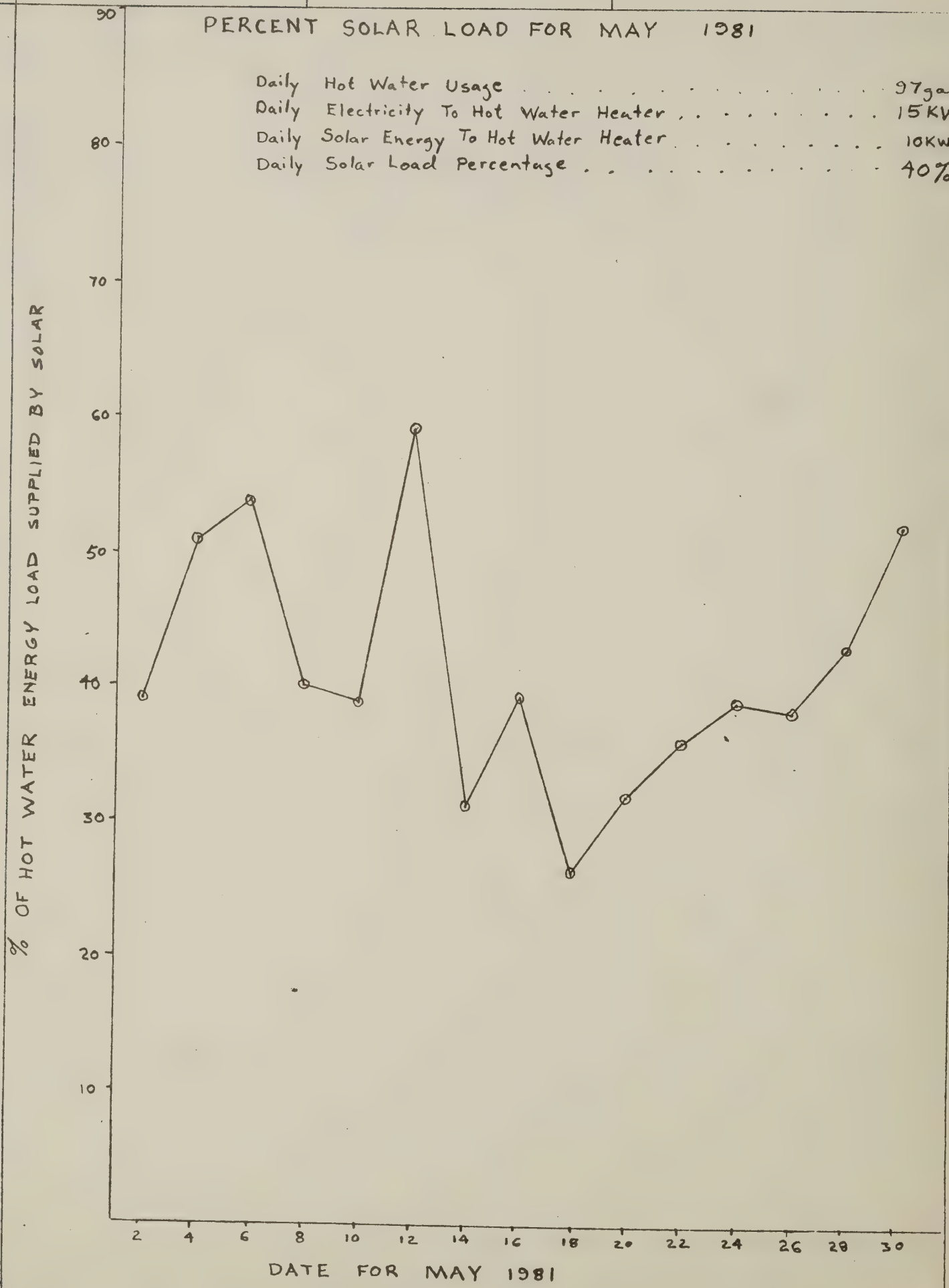


42-381 50 SHEETS 5 SQUARE
42-382 100 SHEETS 5 SQUARE
42-389 200 SHEETS 5 SQUARE
NATIONAL

Dennis Torrence

PERCENT SOLAR LOAD FOR MAY 1981

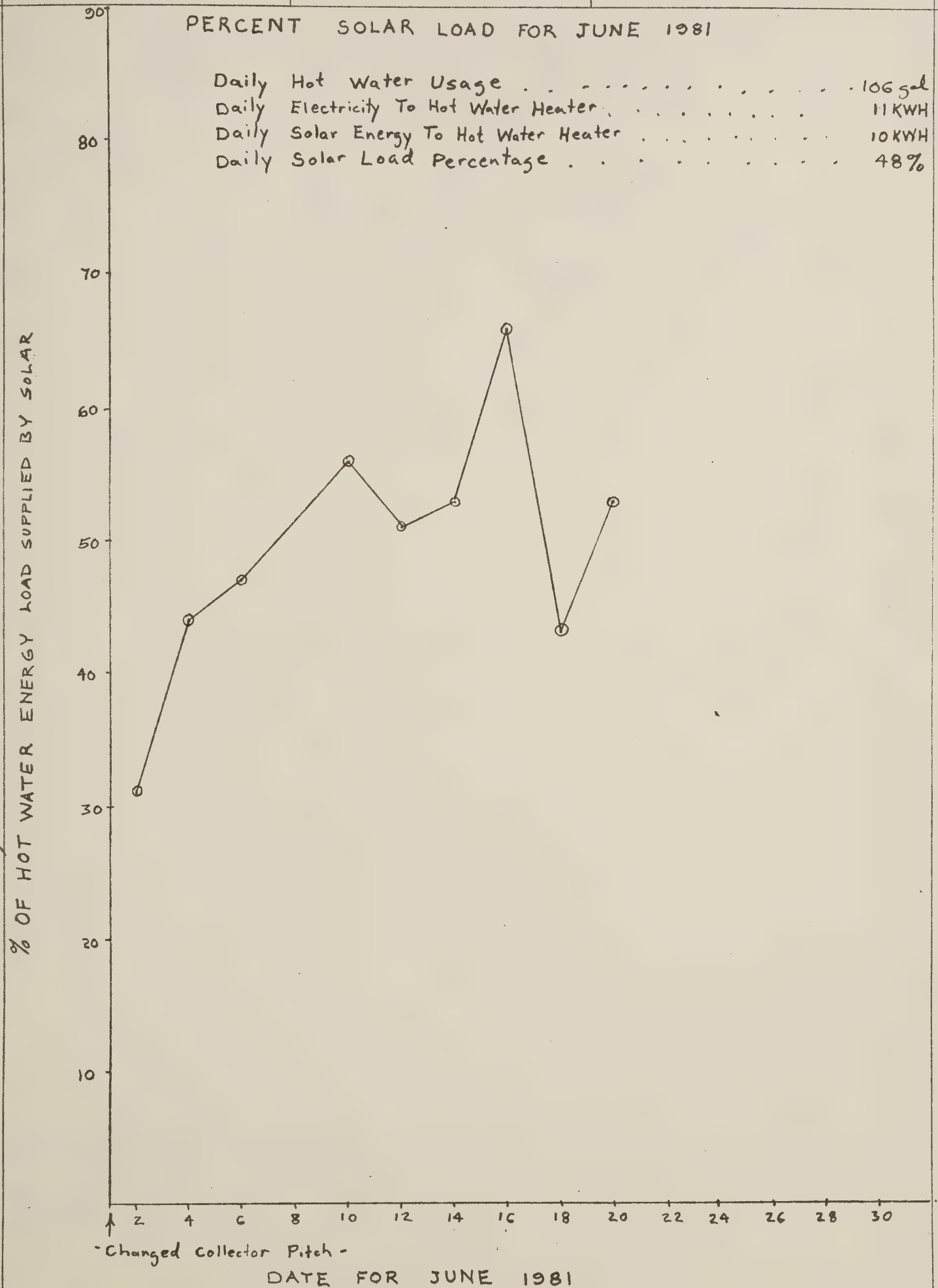
Daily Hot Water Usage 97gal
Daily Electricity To Hot Water Heater 15KWH
Daily Solar Energy To Hot Water Heater 10KWH
Daily Solar Load Percentage 40%



Dennis Torrence

PERCENT SOLAR LOAD FOR JUNE 1981

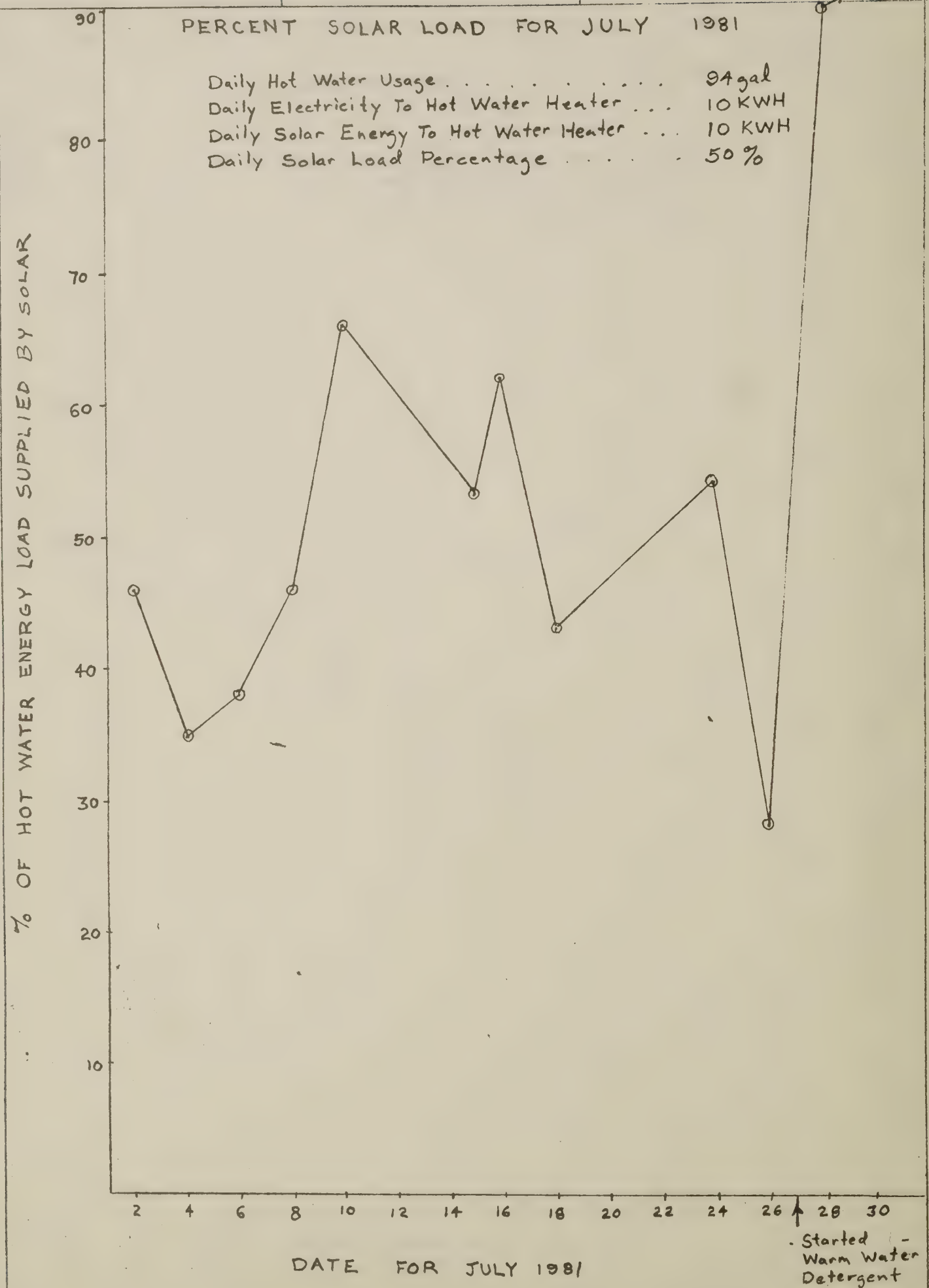
Daily Hot Water Usage	106 gal
Daily Electricity To Hot Water Heater	11 KWH
Daily Solar Energy To Hot Water Heater	10 KWH
Daily Solar Load Percentage	48%



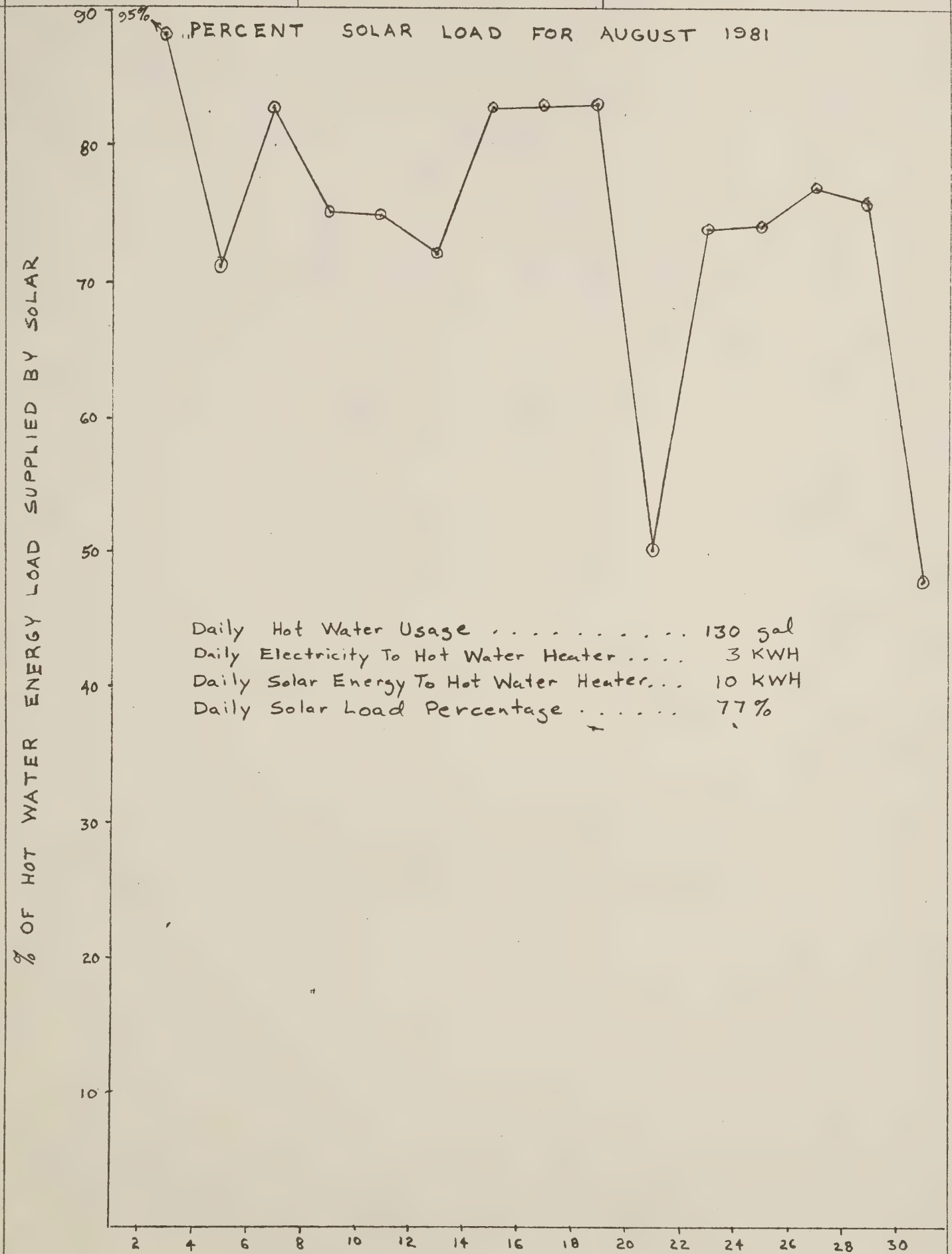
42-381 50 SHEETS 5 SQUARE
42-382 100 SHEETS 5 SQUARE
42-389 200 SHEETS 5 SQUARE
NATIONAL

Dennis Torrence

096%

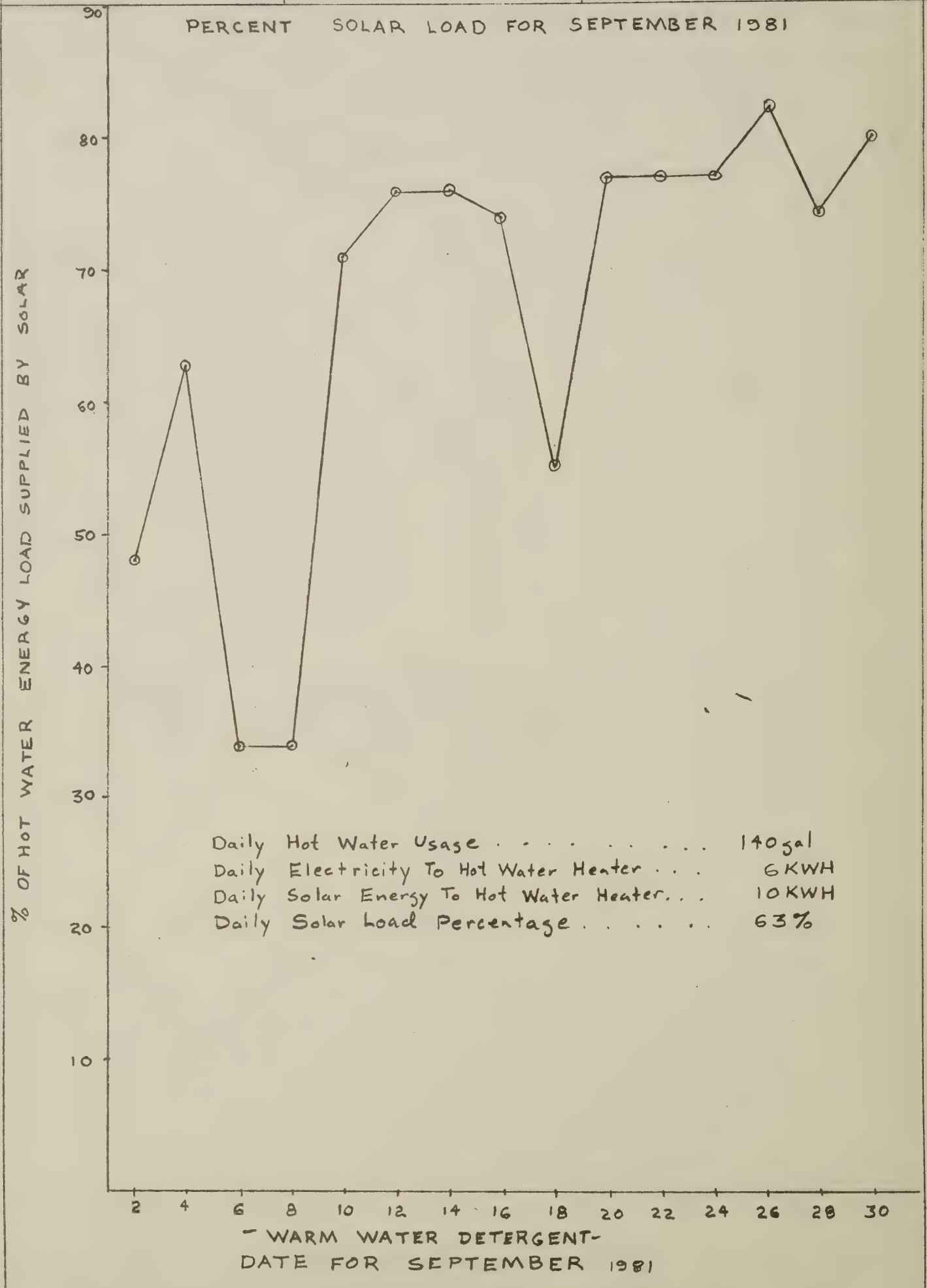


Dennis Torrence



Daily Hot Water Usage . . . . . 130 gal
Daily Electricity To Hot Water Heater . . . . 3 KWH
Daily Solar Energy To Hot Water Heater. . . 10 KWH
Daily Solar Load Percentage 77%

42-381 50 SHEETS 5 SQUARE
42-382 100 SHEETS 5 SQUARE
42-389 200 SHEETS 5 SQUARE
NATIONAL


PERCENT SOLAR LOAD FOR SEPTEMBER 1981
% OF HOT WATER ENERGY LOAD SUPPLIED BY SOLAR
90
80
70
60
50
40
30
20
10
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
- WARM WATER DETERGENT-
DATE FOR SEPTEMBER 1981
Daily Hot Water Usage . . . . . 140 gal
Daily Electricity To Hot Water Heater . . . 6 KWH
Daily Solar Energy To Hot Water Heater. . . 10 KWH
Daily Solar Load Percentage 63%

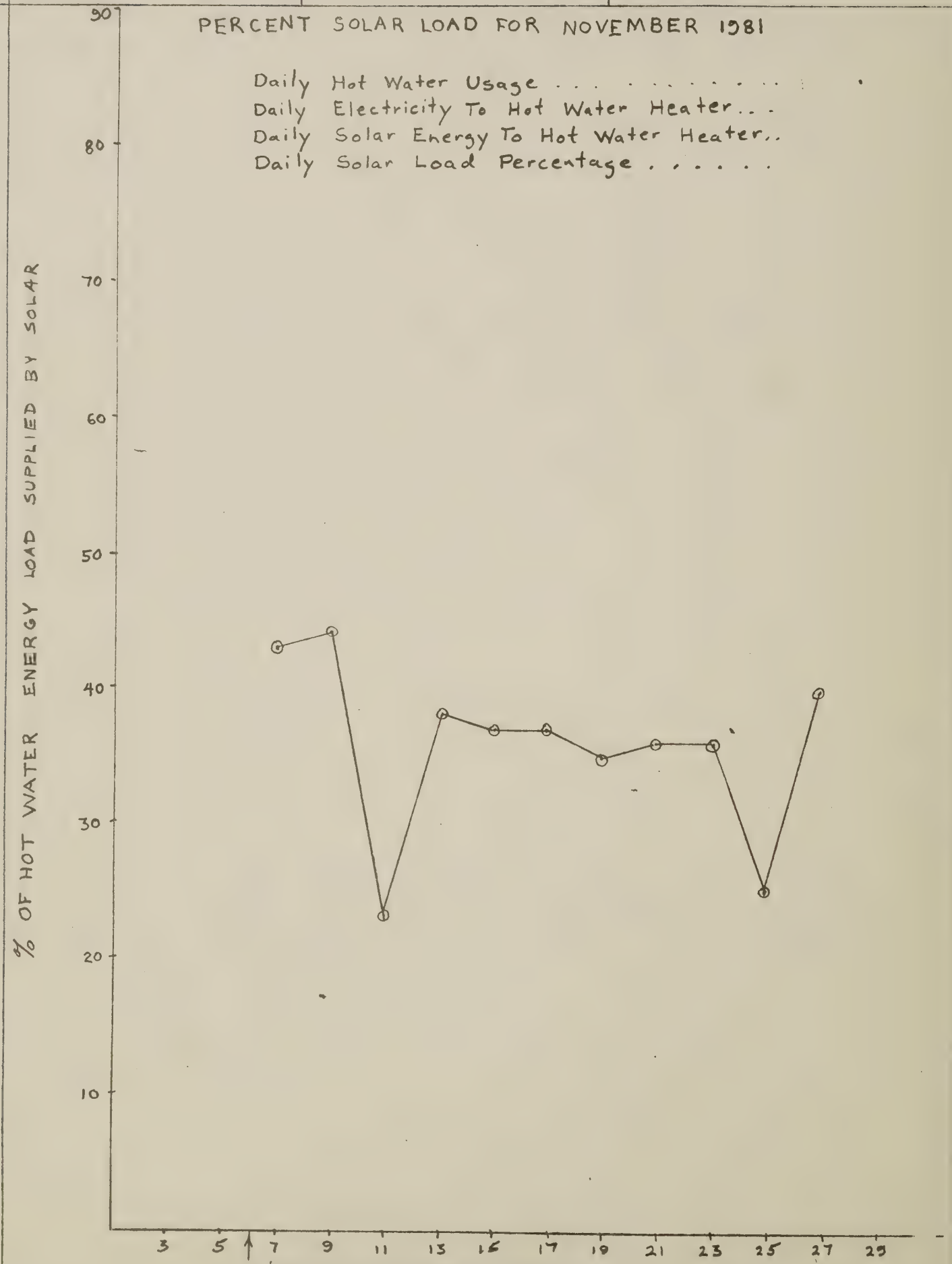
October 1981 Solar System Disconnected

Due To Clogged Drain Line.

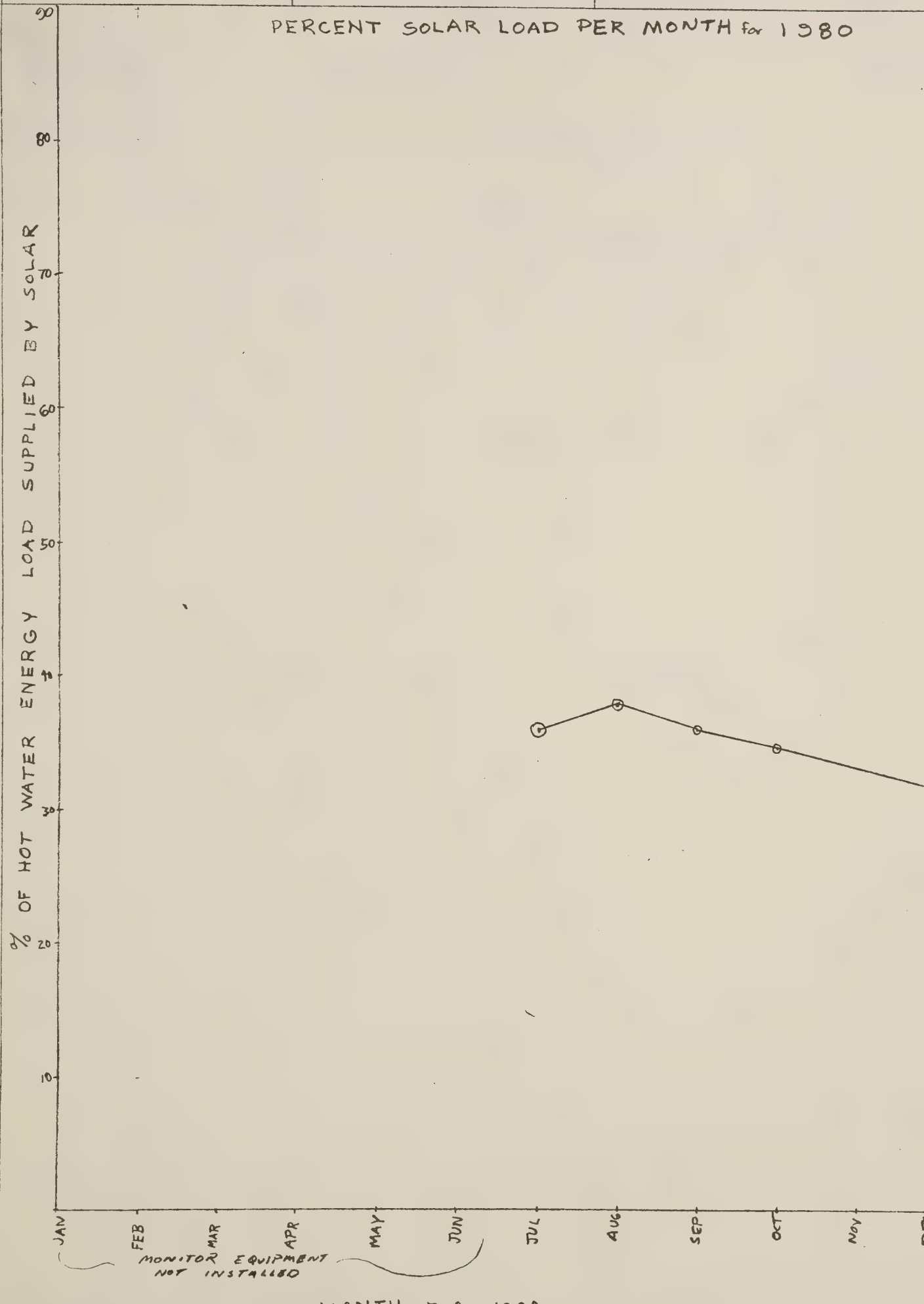
42-381 50 SHEETS 5 SQUARE
42-382 100 SHEETS 5 SQUARE
42-389 200 SHEETS 5 SQUARE
NATIONAL

PERCENT SOLAR LOAD FOR NOVEMBER 1981

Daily Hot Water Usage . . . . . .
Daily Electricity To Hot Water Heater. . .
Daily Solar Energy To Hot Water Heater. .
Daily Solar Load Percentage . . . . . .



Dennis Torrence



Dennis Torrence

PERCENT SOLAR LOAD PER MONTH 1981

Agricultural Engineering

ENERGY MANAGEMENT SERIES

February 13, 1981 ME-123

SOLAR DEMONSTRATION NO. 2
Kitchen Swine Farm
(Phase 1)

H. A. Hughes D. W. Platt
Agricultural Engineering Department

This publication describes a demonstration solar system which has been installed on the Kitchen farm in Southside Virginia. The system is designed to provide a portion of the energy required to heat the floors in a small farrowing house/nursery building. Development of the system was supported by Mr. Kitchen, along with the United States Department of Agriculture, United States Department of Energy and the Virginia Tech Extension Division.

THE FARM

The Kitchen farm is located outside of Courtland, Virginia. Mr. Kitchen, in addition to his swine enterprise, produces cash grain and peanuts. He is a leading young farmer in the area and a strong supporter of extension.

The building is nearly new with an eight crate farrowing house and an attached nursery. The floors in each building are heated by circulating hot water through pipes embedded in the concrete. Each room also is equipped with a conventional heating and ventilation system. Heat for the floor system is provided by the solar system with a conventional electric water heater as a backup.

PROJECT OBJECTIVES

The following objectives governed the design of the system

*Use solar energy to provide a portion of the heat needed to maintain a desirable floor temperature in the creep areas of the farrowing house and

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in the solid floor area of the nursery.

*Evaluate the suitability of a single tank solar water heating system for use on an agricultural application and compare the performance with the two tank system used on Demonstration No. 1.

*Evaluate the potential for solar heat from flat plate collectors for an application which requires a consistent supply of 105 to 120°F water.

*Gather information about the heat loss from concrete slats heated with an embedded pipe.

SYSTEM DESCRIPTION

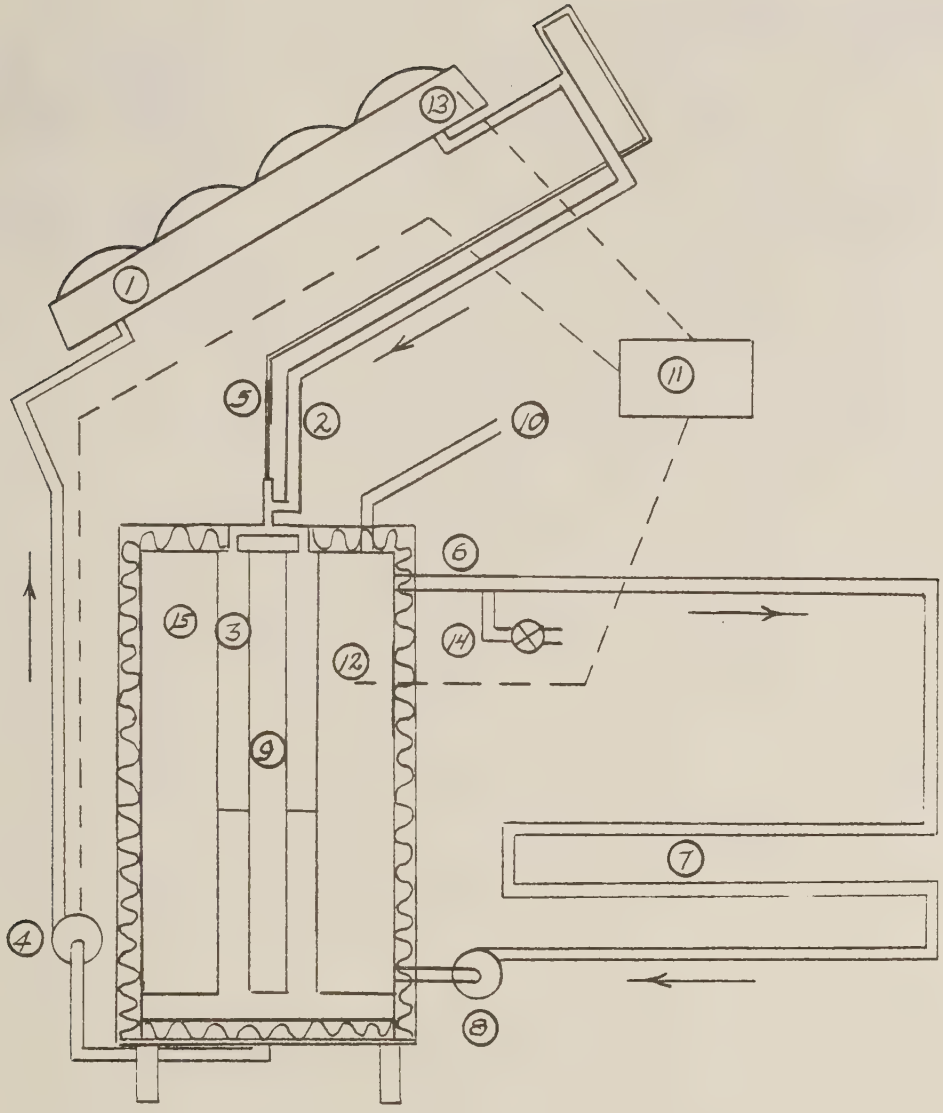
The system, described by an excerpt from the manufacturers literature, is diagramed on the attached sheet. The unit was a purchased item and was installed by the dealer. Collector area is approximately 60 sq. ft.

PERFORMANCE

The system, completely installed and in operation, cost $3,700.00. The system has functioned well to date. Data on performance is being collected but has not yet been analyzed to determine the performance.

COMMENTARY

The only design change which is being considered at this time is an increase in collector area. A recommendation on area needed to supply energy for a heated floor will be issued after all the data has been collected and analyzed.



LEGEND

1. Solar collectors
2. Heated water return line
3. Internal chambers for distilled water(Heat transfer fluid)
4. Collector pump to circulate heat transfer fluid
5. Air bleed line to ensure drain-down
6. Hot water to floor heating system
7. Floor heating circuit(s)
8. Floor heat circulating pump
9. Electric element for stand-by and supplemental heat
10. Cold water supply
11. Differential thermostat to control collector pump
12. Temperature sensor for differential thermostat
13. Temperature sensor for differential thermostat
14. Hot water draw-off
15. Hot water storage(tank includes drain, pressure relief valve and other standard equipment)

Agricultural Engineering

ENERGY MANAGEMENT SERIES

February 10, 1981 ME-122

SOLAR DEMONSTRATION NO. 3
Wampler Turkey Farm
(Phase 1)

H. A. Hughes D. W. Platt
Agricultural Engineering Department

This publication describes a demonstration solar system which has been installed on the Wampler Turkey Farm. The system is designed to: 1) assist the conventional propane fueled heating system to pre-heat the building before the poults are delivered, 2) provide heat during the early part of the brooding phase, and 3) pre-heat ventilation air during the remainder of the brooding period. Development of the system was supported by Mr. Wampler, along with the United States Department of Agriculture, United States Department of Energy, and the Virginia Tech Extension Division.

THE FARM

The Wampler Farm is located near Singers Glen, about 15 miles from Harrisonburg, in the Shenandoah Valley. Mr. Wampler, in addition to being a leader in the turkey industry is a leading breeder of Charolais cattle.

The turkey brooding facility is a nearly new wood framed building 42 x 160 ft. The building was constructed with solar heating in mind and is oriented directly east-west. There are no significant obstructions to the south. The building is well insulated. The ceiling is 2 inches of polystyrene tongue and groove insulation with an R value of 8.0. Sidewalls are solid except for a 2 ft. curtain opening which extends along each sidewall. Double, independently operated curtains are used. Walls, excluding the curtained area, are insulated with 3.5 in. fiberglass batts with an R value of 13. The interior of the wall

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surface is plywood and the entire exterior of the building is clad with aluminum siding and roofing. Heat is supplied by conventional pancake brooders. Three 10,000 cfm fans and the curtain openings are used for ventilation. The building is a well built example of a modern turkey brooding facility in Virginia.

Each flock of 6,500 poults is held in the building for eight to nine weeks. The structure is then cleaned thoroughly and left empty for the remainder of the 13 week (nominal) cycle. The brooding period, depending on weather, is four to five weeks long. Heat is also supplied when the building is empty to prevent freezing of pipes.

PROJECT OBJECTIVES

The following objectives governed the design and construction of the system.

*Use solar energy to pre-heat the building before the poults are received.

*Use solar energy to provide a portion of the heat needed to maintain the building temperature during the initial brooding phase when temperature is highest.

*Pre-heat ventilation air during the brooding period.

*Minimize management changes to facilitate the use of solar heat.

*Evaluate the operating costs of the system.

*Evaluate the suitability of the system for other buildings and identify needed design changes.

SYSTEM DESCRIPTION

The system is designed so that its capabilities "track" the heat requirements of the building. Poultry brooding is characterized by a high peak that load at the start of a brooding cycle. The heat requirement then falls steadily as the building temperature is reduced and as bird heat production increases with increased body weight. Heat is not usually needed after the birds reach four

weeks of age. Thus, there are nine weeks of a typical cycle when heat is not needed (note: in cold weather, the heat may be left on for an additional week).

The solar system designed for this installation uses the dormant period to collect and store heat for the initial high temperature brooding phase. As the heat is extracted from the storage, the storage temperature also drops. However, heat can continue to be supplied to the building during later stages of brooding because the building temperature also decreases.

The solar system has a 640 sq. ft. water type collector and a 12,000 gal. water storage tank insulated with a spray on material with an R=28. On an average day, the collector is expected to pick up about 600 btu/sq. ft., a total of 384,000 btu/day. As the storage warms up, less heat loss from the tank increases until the system reaches a stable temperature. It is expected that the tank temperature will stabilize at about 120°F in winter and about 155°F in summer.

Heat is withdrawn from the tank by circulating water through a heat exchanger located in a duct which channels outside air to a fan which discharges into a flexible ventilation tube. The pump which circulates water through the heat exchanger is controlled by a thermostat which senses the need for heating. During the first seven to ten days of the cycle (until dust becomes a problem) interior air is recycled through the system. The ventilation rate can be controlled by changing the opening where recirculated air is drawn into the duct. As the opening is made smaller, more of the air is drawn in from outside. The building is ventilated by this pressure system and the conventional ventilation system is not used unless a heat or moisture buildup cannot be handled by the solar system.

After about 10 days, the recirculation is stopped and all of the air is drawn in from outside. The system functions to preheat the portion of the

ventilation air that is supplied through the solar system. Additional ventilation is provided by the conventional negative pressure system.

After the brooding season is completed, the heat withdrawal system is shut down, the outside air is blocked off and water does not circulate through the heat exchanger except as needed to prevent freezing. The collectors continue to function, building the temperature of the storage in preparation for the next flock.

PERFORMANCE

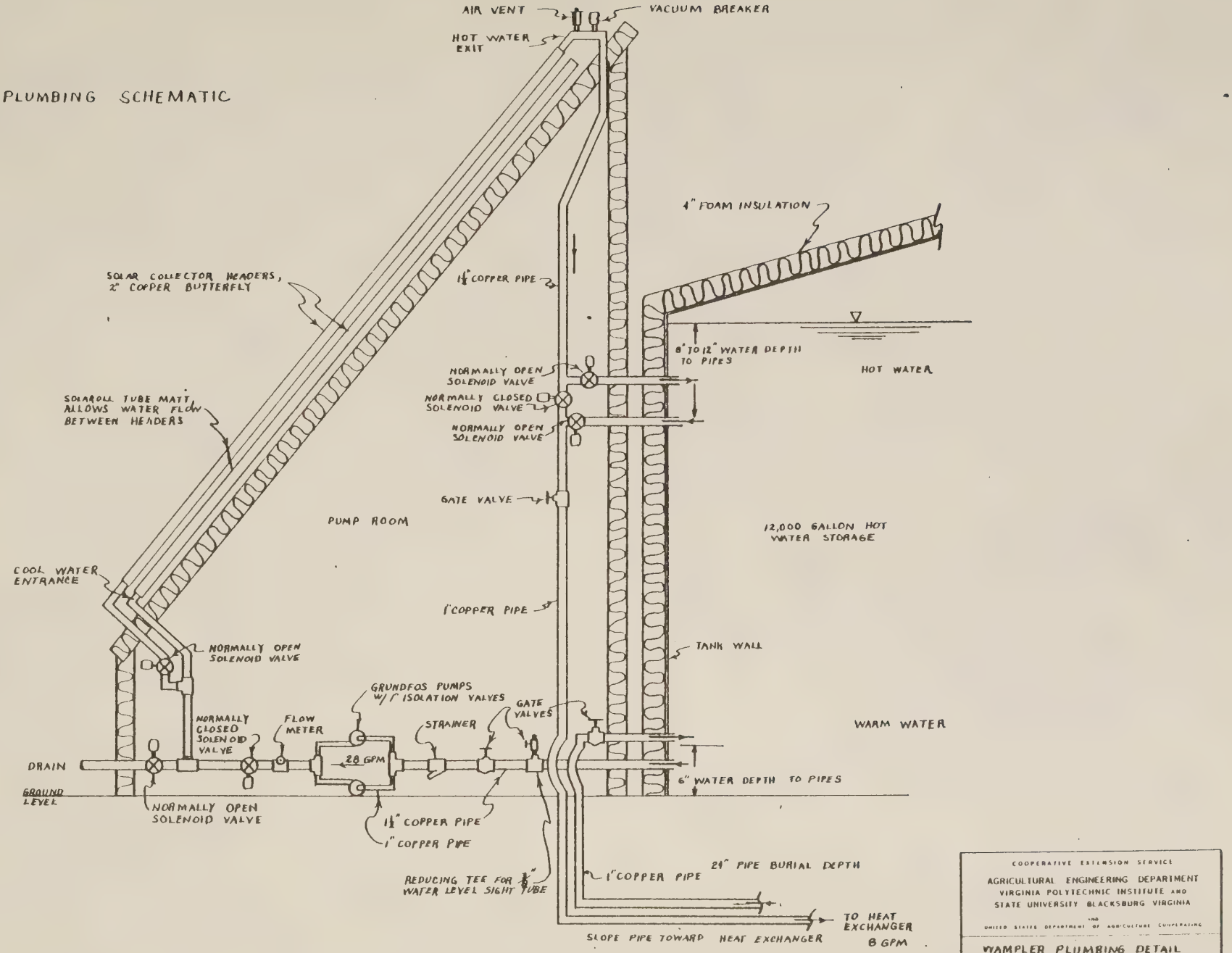
The system, complete and in operation, cost a total of $19,065.85. Performance of the entire system has not yet been completed because of some minor problems with controls. However, the system reached approximately the predicted temperature (120°F in tank on February 10 with flock to be started on February 21). Also, the solar unit was able to heat the building to 65°F when the outside temperature was in the mid-20's, before birds were placed.

COMMENTARY

The system, as originally specified had a micro-processor control which handled control and monitoring of the entire system. However, due to incomplete documentation by the manufacturer, the controller was determined to be very unsatisfactory. It was returned and replaced by several simpler units each controlling single functions.

Also, the freeze protection initially provided was inadequate. Air was drawn through the heat exchanger by the exhaust fans, after the brooding cycle was complete, which froze up the coils. The freeze protection has been improved. Otherwise, the unit seems to have performed as intended. Additional data will be collected to make a more complete evaluation.

PLUMBING SCHEMATIC

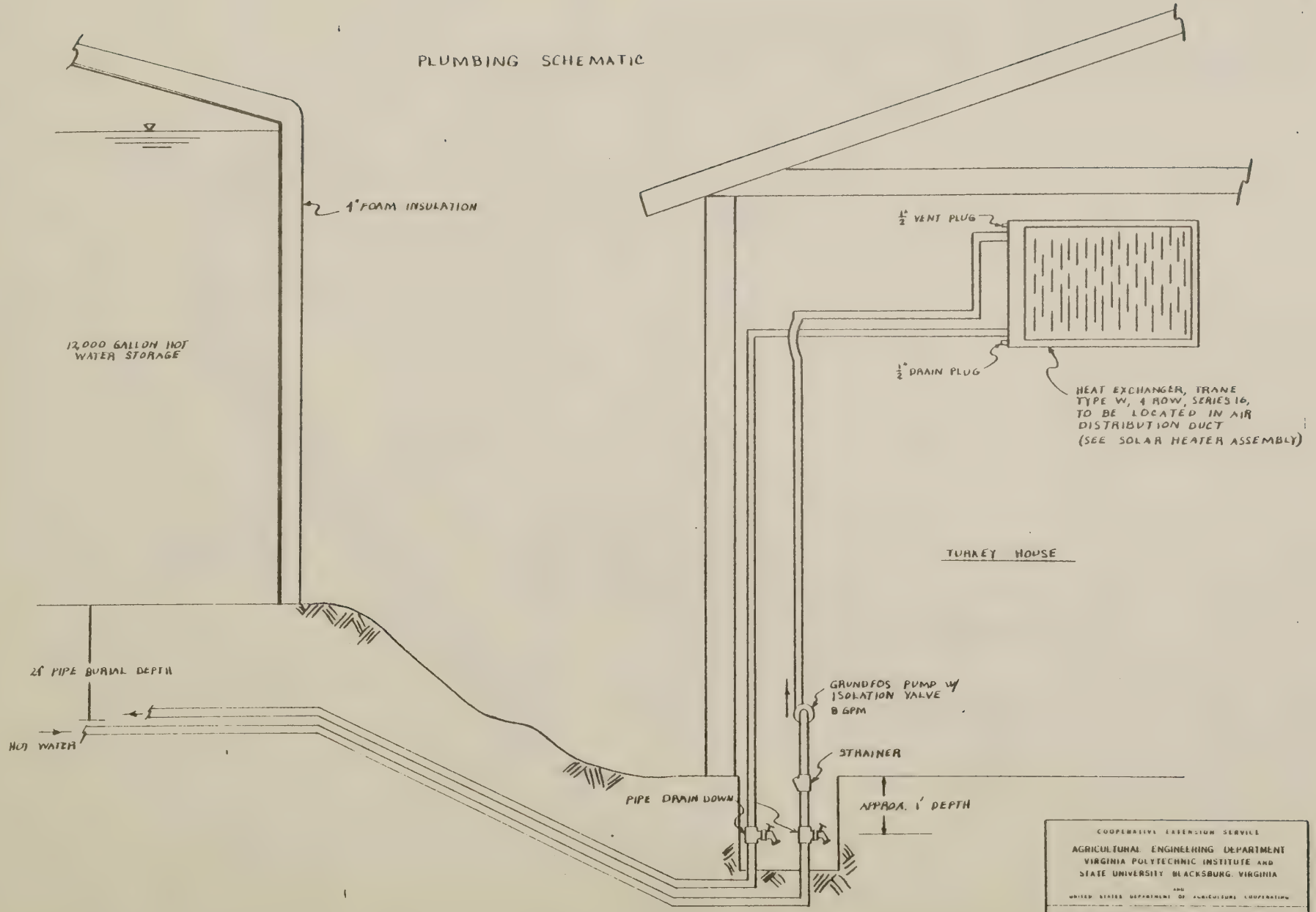


COOPERATIVE EXTENSION SERVICE
AGRICULTURAL ENGINEERING DEPARTMENT
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY BLACKSBURG VIRGINIA
AND UNITED STATES DEPARTMENT OF AGRICULTURE COOPERATING

WAMPLER PLUMBING DETAIL

SCALE	DATE	SHEET 3 OF 8
NTS	6-20-80	
DES BY	DRN BY DWP	CHK BY

PLUMBING SCHEMATIC



COOPERATIVE EXTENSION SERVICE
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VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY BLACKSBURG, VIRGINIA
AND
UNITED STATES DEPARTMENT OF AGRICULTURE COOPERATING

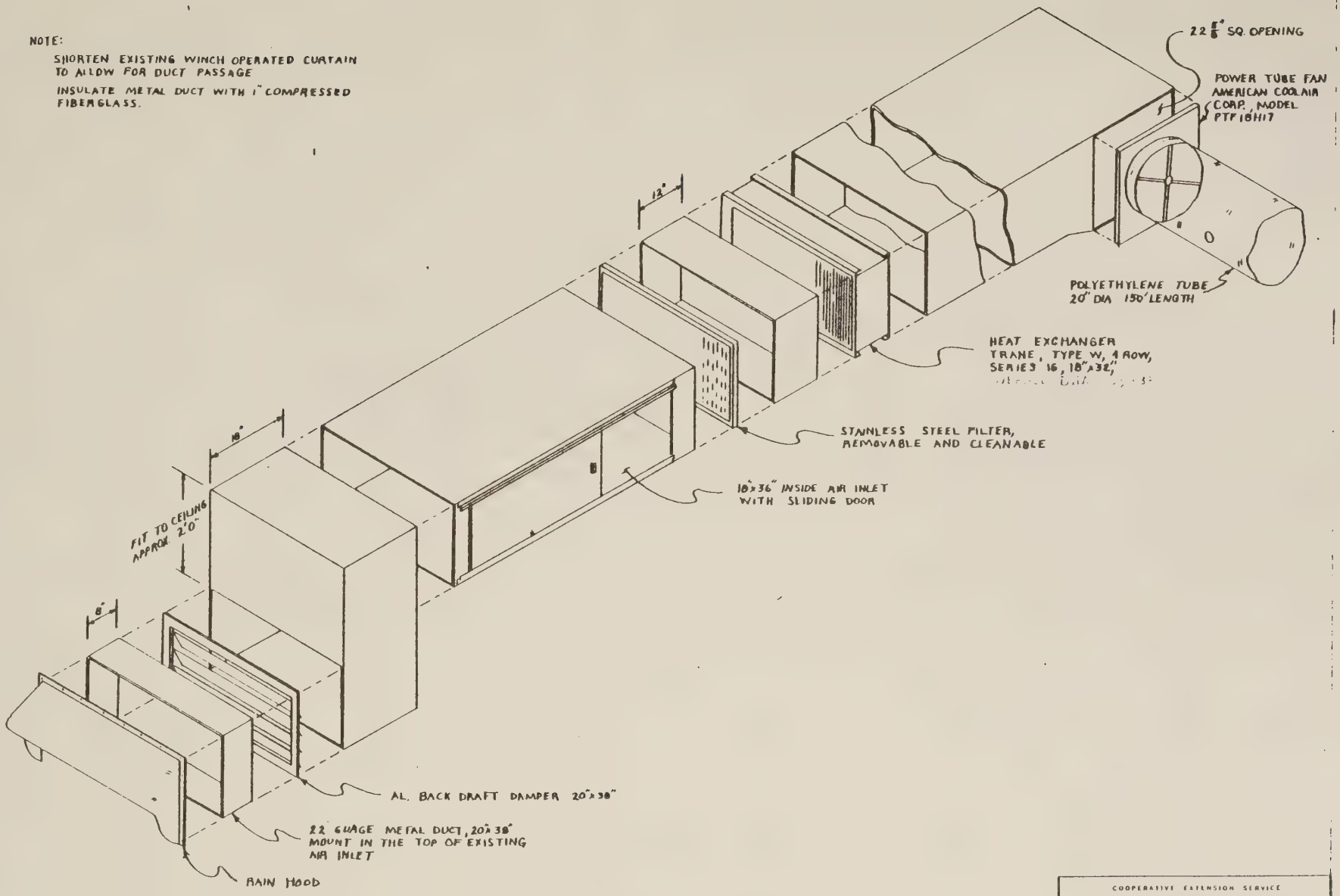
WAMPLER PLUMBING DETAIL

SCALE	DATE	SHEET
NTS	7-3-80	2 OF 8
DES BY	DRN BY DWP	CHK BY

NOTE:

SHORTEN EXISTING WINCH OPERATED CURTAIN TO ALLOW FOR DUCT PASSAGE

INSULATE METAL DUCT WITH 1" COMPRESSED FIBERGLASS.



COOPERATIVE EXTENSION SERVICE

AGRICULTURAL ENGINEERING DEPARTMENT
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY BLACKSBURG VIRGINIA

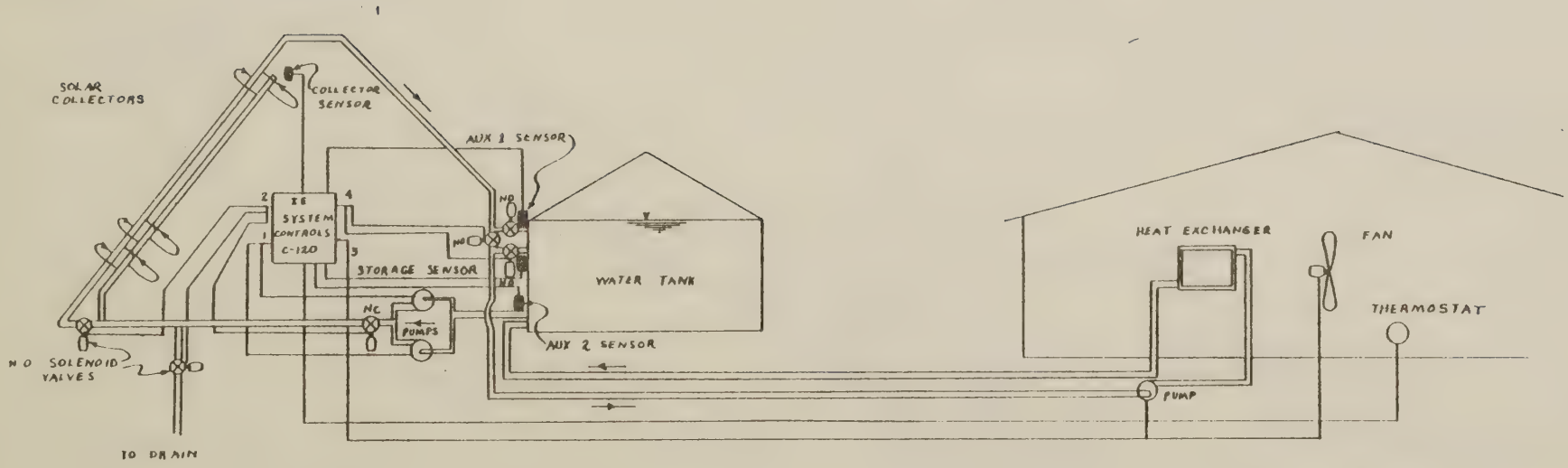
AND

UNITED STATES DEPARTMENT OF AGRICULTURE COOPERATING

WAMPLER SOLAR HEATER ASSEMBLY

SCALE 3/8"=1'-0"		SHEET 8 OF 8
DES BY	DRN BY DWP	CHK BY

CONTROL SYSTEM SCHEMATIC



COOPERATIVE EXTENSION SERVICE		
AGRICULTURAL ENGINEERING DEPARTMENT VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY BLACKSBURG VIRGINIA AND UNITED STATES DEPARTMENT OF AGRICULTURE COOPERATING		
WAMPLER WIRING DETAIL		
SCALE NTS	DATE 1-11-80	SHEET 1 OF 8
DES BY	DRN BY DWP	CHK BY

Agricultural Engineering

ENERGY MANAGEMENT SERIES

November 23, 1981 ME-125

SOLAR DEMONSTRATION NO. 4
Smith Swine Farm
(Phase 1)

H. A. Hughes D. W. Platt

Agricultural Engineering Department

This publication describes a demonstration solar system which has been installed on the Smith swine farm in Southside Virginia. The system is designed to provide a portion of the energy required to heat the floors in a farrowing house/nursery building. Development of the system was supported by Mr. Smith, along with the United States Department of Agriculture, United States Department of Energy, and the Virginia Tech Extension Division.

THE FARM

The Smith farm is located near Martinsville, Virginia. Mr. Smith a progressive young farmer, operates a 90 sow farm and produces much of his own feed.

The swine building is 2 years old with 26 farrowing crates and a 24 x 36 ft. nursery. The orientation is north-south. The walls are constructed of 6 inch block in the bottom portion and stud wall in the top portion. The stud wall contains 3 1/2 inches of fiberglass insulation and 1/2 inch of rigid polyisocyanurate for a total R value of 16. The ceiling is insulated with 5 inches of blown fiberglass and 1 1/2 inches of polyisocyanurate for a total R value of 25. The floors in each room are located over a pit, and are heated by circulating hot water through pipes embedded in the concrete. Heat for the floor system is provided by the solar system with two 50 gallon oil hot water heaters as backups. Additional heat is supplied by electric heat lamps in the farrowing room.

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PROJECT OBJECTIVES

The following objectives governed the design and construction of the system.

* Use solar energy to provide a portion of the heat needed to maintain a desirable floor temperature in the creep areas of the farrowing room and in the solid floor area of the nursery.
* Compare a preheat solar system for radiant floor heating with the one tank system in Demonstration No. 3 and the system in Demonstration No. 5
* Gather information about the heat loss from concrete slats heated with an embedded pipe.

SYSTEM DEMONSTRATION

The system is a 280 gallon solar preheat tank with a 256 square foot drain down water solar collector. The tank is fabricated from 14 gauge steel, with epoxy paint on the inside, and is insulated to R23 with 3 inches of polyurethane foam. The 8 x 32 foot solar collector is site built on a post frame structure. The collector consists of an extruded EPDM rubber tube mat absorber with a fiberglass reinforced plastic glazing.

The solar preheat tank is located in line between the radiant floor heat exit and the oil hot water heaters. Cool water exits from the floor and returns to the bottom of the preheat tank. Cool water exits from the bottom of the preheat tank and circulates through the solar collectors. Solar heated water returns to the top of the preheat tank to the oil heaters. Additional heat is supplied to the water as necessary before circulating it through the radiant floor and back to the preheat tank.

The system is equipped with drain down freeze protection. When the collector temperature drops to 44°F all outside pipes are automatically drained by de-energizing two solenoid valves.

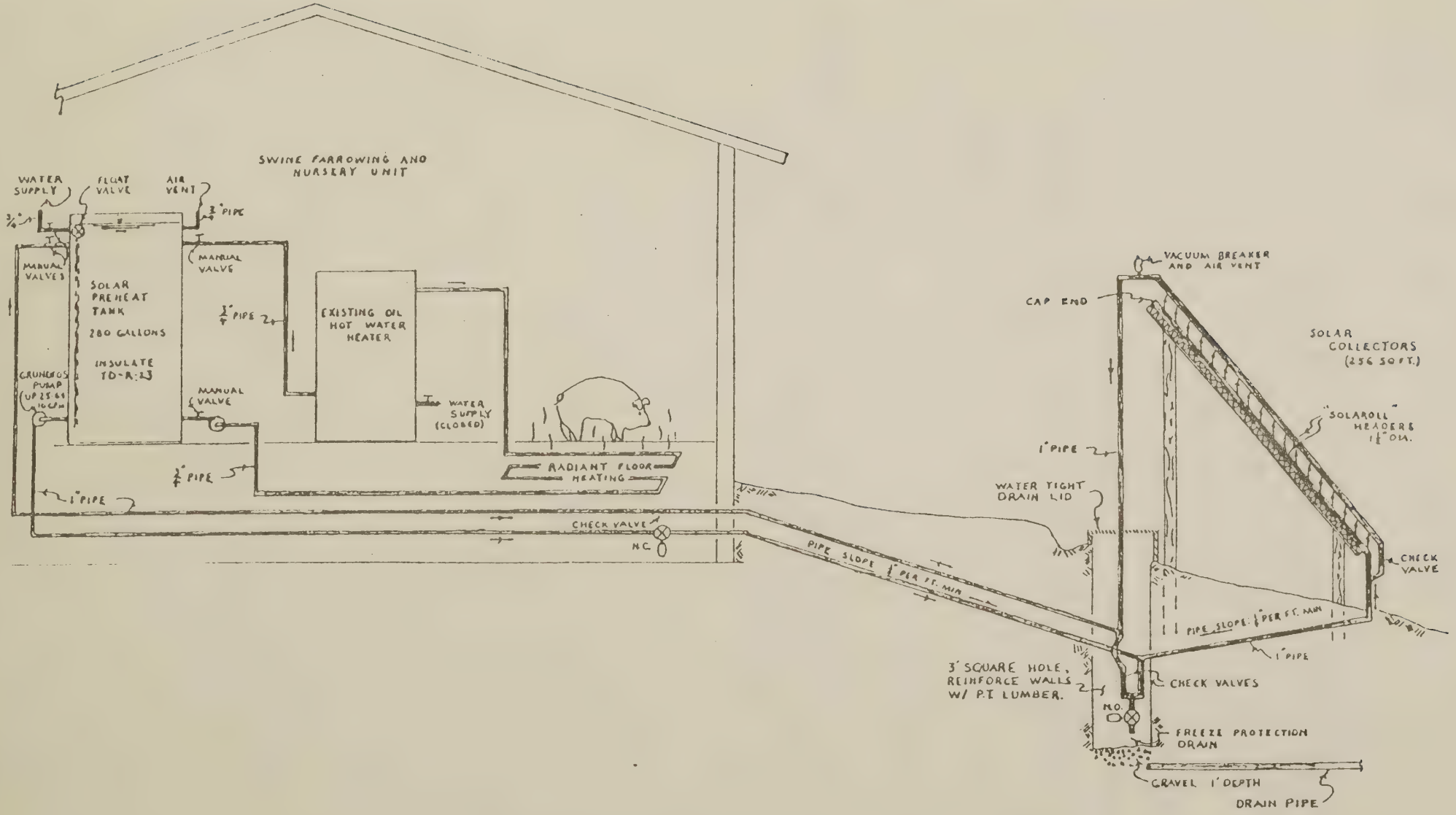
PERFORMANCE

The system, complete and in operation, cost a total of $5,167.92. It was completed in the summer of 1981 and is currently going into its first heating season. The system has functioned well to date, except for a defective pump which has been replaced.

Some monitoring data has been recorded for September and October. The preheat tank temperature has ranged from 85°F to 160°F with an average tank temperature of 120°F. The system has saved Mr. Smith about 65 gallons of oil by delivering over 5 million BTU's to the radiant floor heating system during the two month period.

COMMENTARY

No design changes are being contemplated at this time. Additional monitoring equipment will be installed and a more complete evaluation will be made.



SOLAR RADIANT FLOOR HEAT FOR SWINE

Agricultural Engineering

ENERGY MANAGEMENT SERIES

November 23, 1981 ME-127

SOLAR DEMONSTRATION NO. 5
Whitley Swine Farm
(Phase 1)

H. A. Hughes D. W. Platt
Agricultural Engineering Department

This publication describes a demonstration solar system which has been installed on the Whitley swine farm in Southside Virginia. The system is designed to provide a portion of the energy required to heat the floor in a farrowing house. Development of the system was supported by Mr. Whitley, along with the United States Department of Agriculture, United States Department of Energy and the Virginia Tech Extension Division.

THE FARM

The Whitley farm is located near Sedley, Virginia about 5 miles north of Franklin. Mr. Whitley, a progressive young farmer, operates an impressive 275 sow farm. He produces his own feed along with a cash crop of peanuts.

The farrowing house is 2 years old with two 28 crate farrowing rooms. The orientation is east-west. The walls are constructed of insulation filled blocks in the bottom portion and stud wall in the top portion. The stud wall and ceiling are insulated with 6 inches of fiberglass insulation with an R value of 19. The floors in each room are located over a flushing pit and are heated by circulating hot water through pipes embedded in the concrete. Heat for the floor is provided by the solar system and a 40 gallon gas hot water heater. Additional heat is supplied by gas space heaters and heat lamps.

PROJECT OBJECTIVES

The following objectives governed the design and construction of the system.

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* Use solar energy to provide a portion of the heat needed to maintain a desirable floor temperature in the creep areas of the two farrowing rooms.
* Compare this system with the preheat solar systems and Demonstration System No. 2.
* Gather information about the heat loss from concrete slats heated with an embedded pipe.

SYSTEM DESCRIPTION

The system is composed of two-550 gallon water tanks with a 384 square foot drainback water solar collector. The tanks are molded from a heat resistant plastic and insulated to R32 with 8 inches of expanded polystyrene. The 8 x 48 foot solar collector was site built on a post frame structure. The tanks are located in a room constructed beneath the collector. The collector consists of an extruded EPDM-rubber tube mat absorber with a fiber-glass reinforced plastic glazing.

The system has two modes of operation (i.e. a conventional mode and a solar mode). The heating mode is controlled by a thermostat and three electric valves. During the conventional mode, the solar tank temperature is below the desired temperature, and the radiant floor heating system is supplied with water from the gas hot water heater. During the solar mode, used when the solar collectors have heated the water sufficiently, the valves are energized, and the radiant floor heating system is supplied with water from the solar tanks. During the winter one solar tank may be disconnected and drained in order to achieve the desired high temperature.

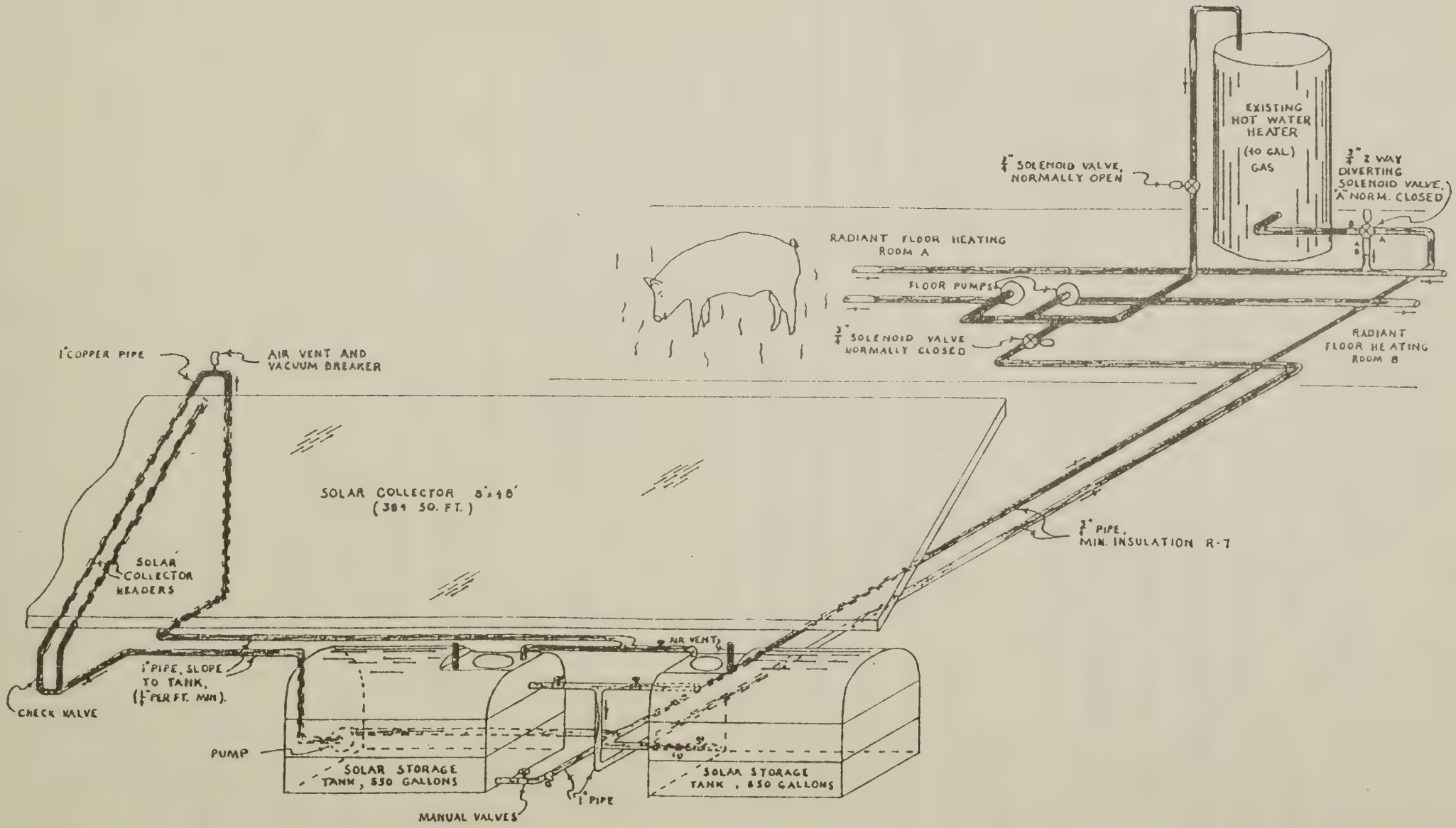
Freeze protection is accomplished by allowing the solar collector water to drain back into the solar tanks whenever the collector pump is off. Heat tape is used to protect the pipes below the tank water level.

PERFORMANCE

The system, complete and in operation, cost a total of $6,794.14. It was completed in the summer of 1981 and is currently going into its first heating season. The system has functioned well to date, except for an occasional pump priming problem. Monitoring data is incomplete, however the system has run in the solar heating mode during most summer nights.

COMMENTARY

No major design changes are being contemplated at this time, except to solve the pump priming problem. At the end of November, one of the two solar tanks will be disconnected and drained in order to allow for the seasonal change. Additional monitoring equipment will be installed, complete data will be recorded and a system evaluation will be made.



SOLAR RADIANT FLOOR HEAT FOR SWINE

Agricultural Engineering

ENERGY MANAGEMENT SERIES

November 23, 1981 ME-128

SOLAR DEMONSTRATION NO. 6
Davis Swine Farm
(Phase 1)

H. A. Hughes D. W. Platt

Agricultural Engineering Department

This publication describes a demonstration solar system which has been installed on the Davis farm in the Eastern Shore of Virginia. The system is designed to preheat ventilation air during the heating period and cool the ventilation air during the summer in a farrowing house. Development of the system was supported by Mr. Davis, along with the United Stated Department of Agriculture, United States Department of Energy, and the Virginia Tech Extension Division.

THE FARM

The Davis farm is located in Davis Wharf, Virginia about 5 miles west of Exmore. Mr. Davis and his brother operate a swine farm and produce their own feed.

The 26 crate farrowing house is oriented in the east-west direction. Three exhaust fans are mounted on the south side. Heat lamps are used in the farrowing crates.

PROJECT OBJECTIVES

The following objectives governed the design and construction of the system.

* Use solar energy to preheat the ventilation air in the farrowing room during the heating season and also stabilize the daily temperature fluctuation.
* Use the system to cool the ventilation air in the farrowing room during the hot summer days.

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* Compare the flat fiberglass double glazing with the corrugated fiberglass and plastic vinyl glazing in Demonstrations No. 7 and 8.

SYSTEM DESCRIPTION

The system constructed on the Davis farm is similar to that originated by Spillman at Kansas State University. The unit is a 7 x 56 foot block wall which functions are both solar collector and storage. The 16 inch thick wall is located along the south side of the farrowing room. It consists of 4 x 8 x 16 inch solid blocks with 1/4 inch vertical air spaces between blocks. The south face of the block is painted flat black. The wall is double glazed with flat fiberglass. The end walls and ceiling are sealed and insulated. Ventilation air is preheated as it passes through the double glazed block wall. The air enters the building through the conventional eave inlet.

The system is also equipped for summer cooling. An air duct with a network of 5 motorized shutters is located in the ceiling of the solar addition and an exhaust fan is located in one of the end walls. Plywood panels are hung to shade the wall during the summer. At night the end wall fan circulates cool night air through the wall to cool the blocks. Ventilation air by-passes the wall and enters the room through the air duct. During the day the end wall fan is turned off and the ventilation air is cooled by passing through the cooled blocks.

PERFORMANCE

The complete system was constructed by a local construction company for $9,246.35. It was completed in the spring of 1981 and is currently going into its first heating season. No monitoring equipment has been installed.

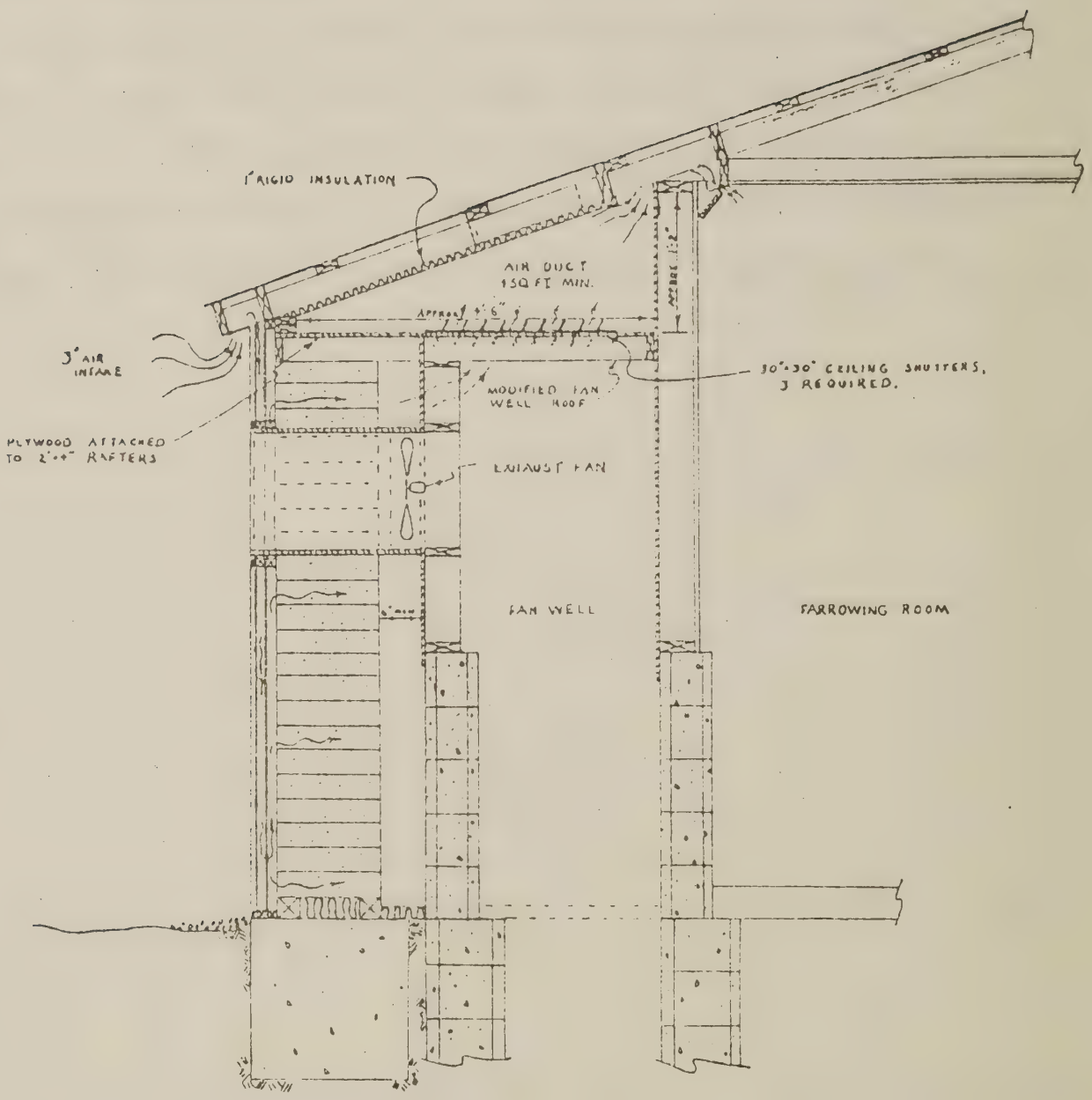
COMMENTARY

No design changes are being contemplated at this time. Monitoring equipment will be installed and a system evaluation will be made.

The summer cooling option made the system complex by adding the motorized shutters, exhaust fan, and timer.

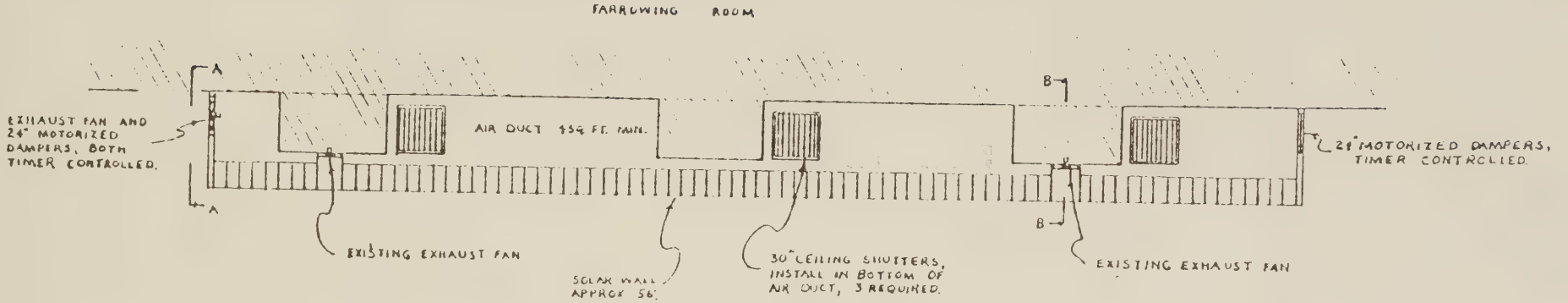
Based on experience with Spillman walls at this and other sites, it is recommended that Spillman walls should be built by the individual, rather than by a construction company. The construction is labor intensive, but little skilled work is involved and the involvement of a professional builder may simply increase the cost without a concommitant improvement in performance.

SECTION B-B



SOLAR HEATING & COOLING ADDITION FOR SWINE FARROWING

PLAN VIEW



NOTE:

FOR SUMMER COOLING OPERATION;

- COVER SOUTH FACING WALL W/ SHUTTER PANELS.
- USE 24 HR TIMER TO CONTROL END WALL EXHAUST FAN AND TWO 24" MOTORIZED DAMPERS.
- NIGHT - END WALL EXHAUST FAN "ON" AND MOTORIZED DAMPERS OPEN.
- DAY - END WALL EXHAUST FAN "OFF" AND MOTORIZED DAMPERS CLOSED.

SOLAR HEATING & COOLING ADDITION FOR SWINE FARROWING

Agricultural Engineering

ENERGY MANAGEMENT SERIES

November 23, 1981 ME-126

SOLAR DEMONSTRATION NO. 7
Bryan & Sons Swine Farm
(Phase 1)

H. A. Hughes D. W. Platt
Agricultural Engineering Department

This publication describes a demonstration solar system which has been installed on the Bryan & Sons swine farm in Central Virginia. The system is designed to preheat ventilation air in a farrowing room. Development of the system was supported by Mr. Bryan & Sons, along with the United States Department of Agriculture, United States Department of Energy, and the Virginia Tech Extension Division.

THE FARM

The Bryan & Sons farm is located near Dillwyn, Virginia about 20 miles north of Farmville. Mr. Bryan and his two sons operate a 55 sow farm. They produce their own feed along with a cash crop of wheat. In addition, they raise cattle.

The swine building is 11 years old with a 16 crate farrowing room and a nursery. The orientation is east-west and all exhaust fans are on the north side. The walls are constructed of 8 inch insulated blocks. The ceiling is insulated with 4 inches of fiberglass insulation with an R value of 13. The building is located over a partial pit. The farrowing room is heated with heat lamps.

PROJECT OBJECTIVES

The following objectives governed the design and construction of the system.

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* Use solar energy to preheat the ventilation air in the farrowing room and also stabilize the daily temperature fluctuation.
* Use conventional materials to construct a do-it-yourself system.
* Compare the corrugated fiberglass and plastic vinyl glazing with the flat fiberglass double glazing in Demonstration No. 6.

SYSTEM DESCRIPTION

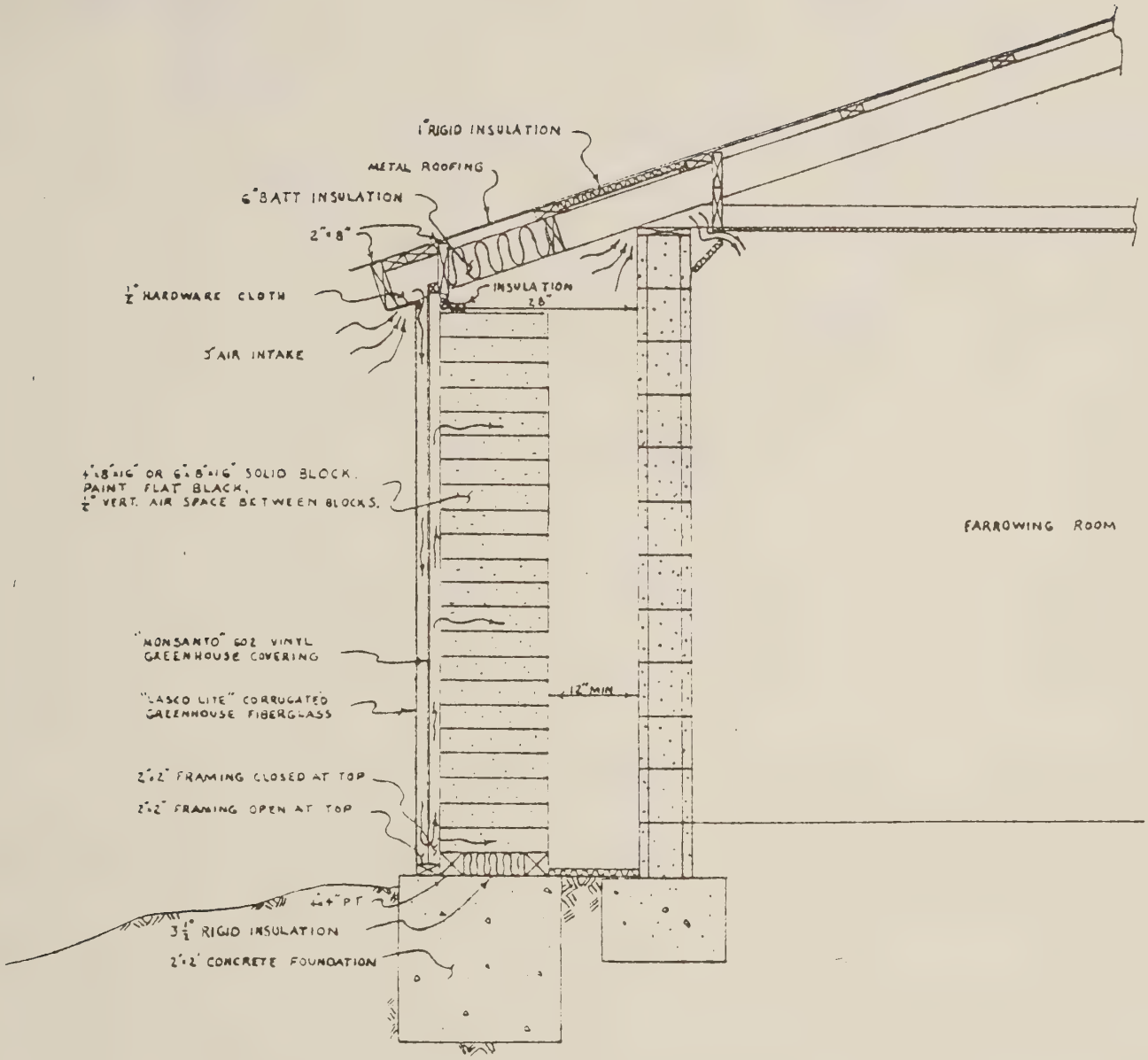
The system constructed on the Bryan & Sons farm is similar to that originated by Spillman at Kansas State University. The unit is an 8 x 46 foot block wall which functions as both the solar collector and storage. The 16 inch thick wall was installed under an existing roof overhang. It consists of 4 x 8 x 16 inch solid blocks with 1/4 inch vertical air spaces between blocks. The south face of the block is painted flat black. The wall is double glazed with vinyl greenhouse covering on the inside and corrugated fiberglass on the outside. The end walls and ceiling are sealed and insulated. Ventilation air is preheated as it passes through the double glazed block wall. The air enters the farrowing room through the conventional eave inlet. A curtain is used to shade the wall during the summer.

PERFORMANCE

The complete system, utilizing farm labor, cost a total of $2,926.50. It was completed in the summer of 1981 and is currently going into its first heating season.

COMMENTARY

No design changes are being contemplated at this time. Monitoring equipment will be installed and a system evaluation will be made. Recommendations will be made to install more ceiling insulation in the building.



SOLAR WALL ADDITION FOR SWINE FARROWING

Agricultural Engineering

ENERGY MANAGEMENT SERIES

November 24, 1981 ME-129

SOLAR DEMONSTRATION NO. 8
Robinson Farm
(Phase 1)

H. A. Hughes D. W. Platt

Agricultural Engineering Department

This publication describes a demonstration solar system which has been installed on the Robinson farm in Southside, Virginia. The system is designed to preheat ventilation air in a farrowing room. Development of the system was supported by Mr. Robinson, along with the United States Department of Agriculture, United States Department of Energy, and the Virginia Tech Extension Division.

THE FARM

The Robinson farm is located near Skippers, Virginia about 5 miles south of Emporia. Mr. Robinson operates a large farm and is involved in almost all aspects of farming.

The swine building, a 20 crate factory built farrowing house and attached nursery, is 8 years old. The orientation is north-south. The walls and ceiling are insulated with 1 inch urethane with a R value of 8. The farrowing room is heated with gas space heaters and heat lamps.

PROJECT OBJECTIVES

The following objectives governed the design and construction of the system.

* Use solar energy to preheat the ventilation air in the farrowing room and to stabilize the daily temperature fluctuation.
* Adopt the Spillman solar wall heating system to a pre-manufactured swine building which is popular in the area.

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* Utilize the south end wall on a north-south oriented building.
* Compare the corrugated fiberglass and plastic vinyl glazing with the flat fiberglass double glazing in Demonstration No. 6.

SYSTEM DESCRIPTION

The system constructed on the Robinson farm is similar to that originated by Spillman at Kansas State University. The unit is a 6 x 48 foot block wall which combines as the solar collector and storage. The 16 inch thick wall is built across the south end of the building and extends 12 feet on each side of the building. It consists of 4 x 8 x 16 inch solid concrete blocks with 1/4 inch vertical air spaces between blocks. The south face of the block is painted flat black. The wall is doubled glazed with vinyl greenhouse covering on the inside and corrugated fiberglass on the outside. A post frame structure encloses the block wall extensions. The structure is sealed and insulated. An 18 inch diameter, 1/3 horsepower, variable speed fan is located between the solar wall and the farrowing room. The fan pulls the ventilation air through the double glazed block wall causing it to be preheated. It is then delivered down an insulated air plenum located in the ridge of the building and distributed through 6 registers.

PERFORMANCE

The complete system was constructed by a local construction company for $7,811.00. It was completed in the summer of 1981 and is currently going into its first heating season. No monitoring equipment has been installed.

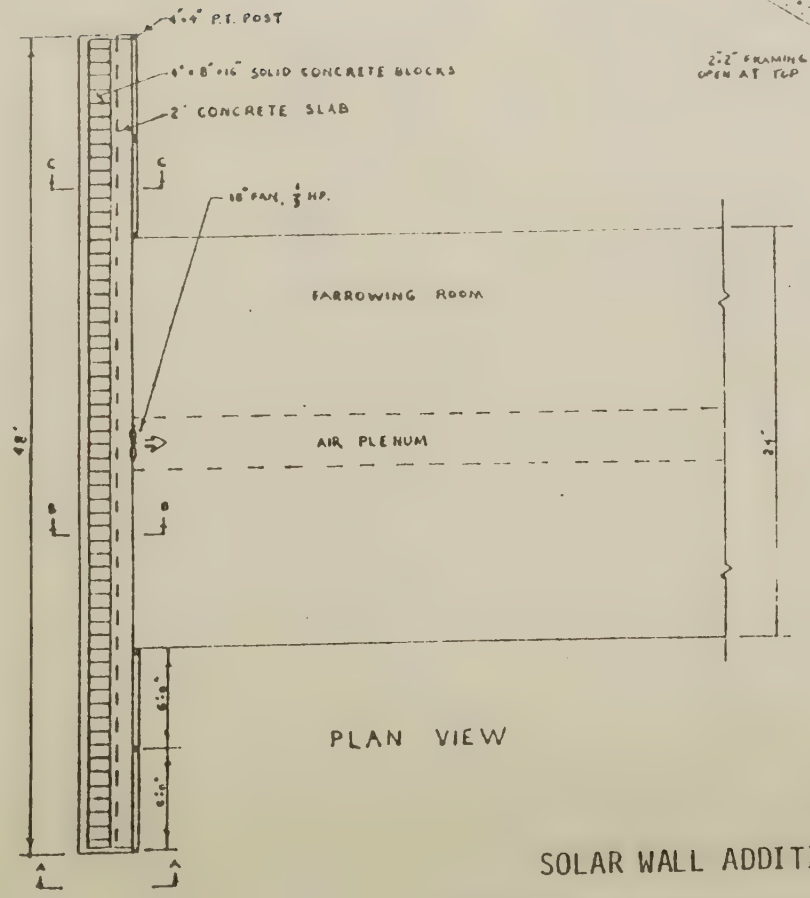
COMMENTARY

No design changes are being contemplated at this time. The variable speed fan allows the air flow rate through the wall to be varied. Monitoring equipment will be installed and a system evaluation will be made. The optimum air flow rate through the wall will be determined.

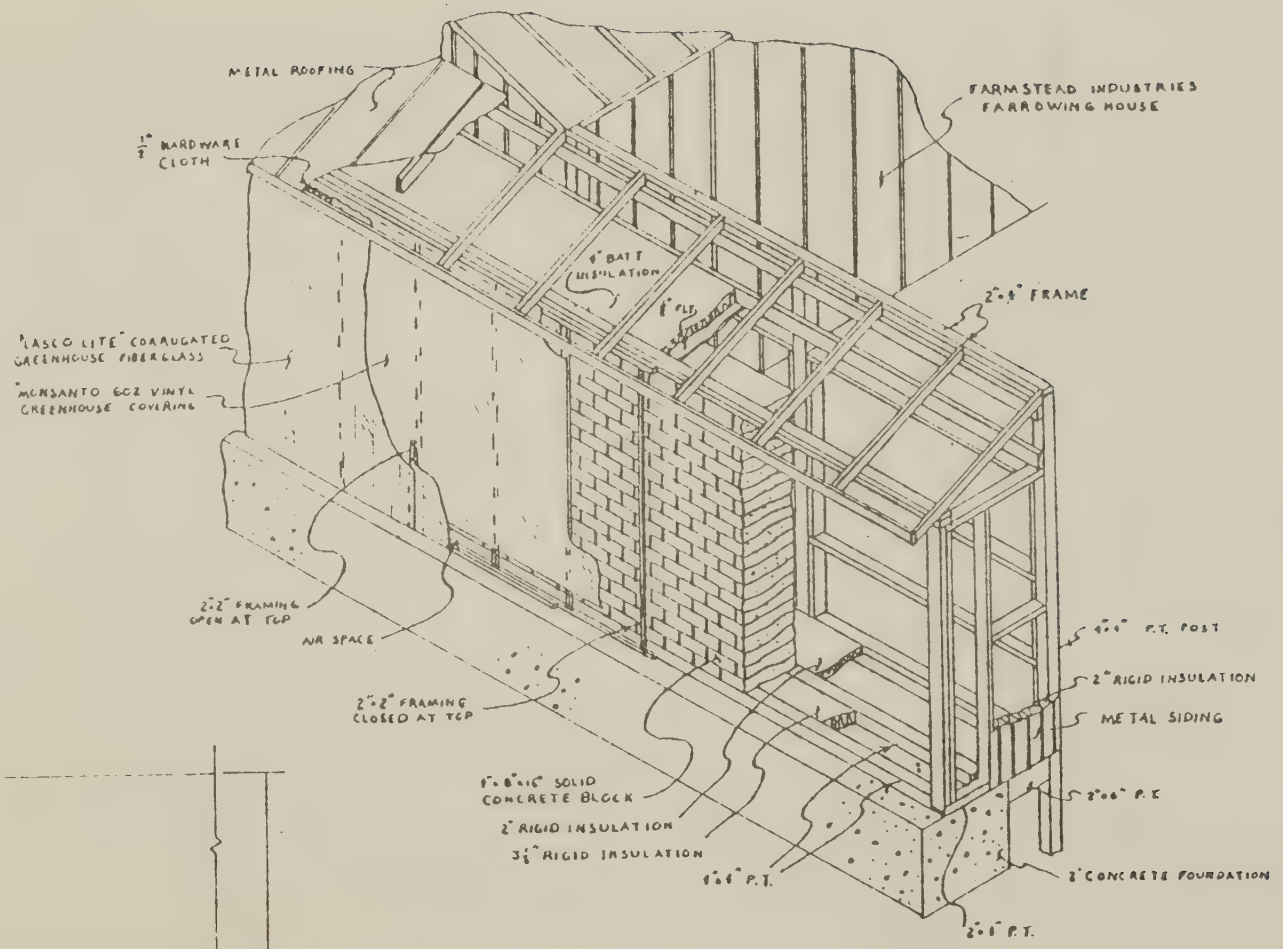
Based on experience with Spillman walls at this and other sites, it is recommended that Spillman walls should be built by the individual, rather than by a construction company. The construction is labor intensive, but little skilled work is involved and the involvement of a professional builder may simply increase the cost without a concommitant improvement in performance.

NOTE:

- SOLAR WALL ADDITION CONSTRUCTED ON SOUTHERN END OF BUILDING.
- BACK WALL COVERED WITH METAL SIDING & FILLED WITH 3½" BATT INSULATION WITH VAPOR BARRIER.



PLAN VIEW



ISOMETRIC VIEW

SOLAR WALL ADDITION FOR SWINE FARROWING

APPENDIX C

Sample Materials List and Billing

Bryan Farm

Bills For Mr B.H. Bryan & Sons Solar Project

	Digging footing		75.00 ✓
	Concrete for footing	7 1/2 yds	374.40 ✓
12	4"X4"X8' Pt. lumber		60.00 ✓
2	Rolls Insulation		42.90
5	lb Nails		3.25
12	2"X8"X12' lumber		90.00
13	2'X4" studs		22.75
	Tax		6.35
1500	4"X8"X16" solid Blocks		1140.00
50	4"X8"X16" solid Blocks		35.36
37	4"X8"X16" solid Blocks		28.86
3	Gal. Flate Black Paint		50.25
4	Tubes silcone Caulking		26.36
1	box staples		1.55
17	ft. Hardware Cloth		12.75
6	pc 8 ft sheet Rock corners		7.80
	Tax		5.13
10	pc. 2"X8"X1" styrofoam		42.00
50	pc. 2"X2"X8' lumber		48.00
	Tax		3.60
5	pc. 2'X8'X1" styrofoam		21.00
4	1"X2"X8' fir lumber		2.24
6	2"X4"X8' P.T. lumber		14.87
6	2"X6"X8' # 2 Common lumber		15.60
2	1/2"X4"X8" apt. plywood		34.10
2	2'X8'X1" Styrofoam		8.40
	Tax		1.70
	Fiberglass panels		251.68

Bills For Mr. B.H. Bryan & Sons Solar Project

Quantity	Description	Amount
	Footing for solar system	75.00
2	Rolls Insulation	42.00
5 lbs	Nails	3.25
12	2"x8"x12'	90.00
13	2"x4" studs	22.75
	tax	6.35
3 gal	Flat Black paint	50.85
4	Silicon Caulking	26.36
37	4" Solid Block	28.86
1	Box staples	1.55
17'	Hardware Cloth (Ratwire)	12.75
6	8' Sheet Rock corners	7.80
	Tax	5.13
7½ yds³	Concrete footing	374.40
12	4"x4"x8 P.T Lumber	60.00
1,500	Solid Block	1,140.00
50	Solid Block	35.36
2	½"x4'x8' Ext. Plywood	34.10
2	2'x8'x1" Styrofoam	8.40
	Tax	1.70
10	2'x8'x1" styrofoam	42.00
50	2"x2"x8' lumber	48.00
5	2'x8'x1" styrofoam	21.00
4	1"x2"x8' lumber	2.24
	total this page	2,140.75

(cont)

Bills cont.

Quantity	Description	Amount
6	2"x4"x8' P.T lumber	14.87
6	2"x6"x8' #2 lumber	15.60
	Tax	3.60
11	8' clear skylight fiberglass panel w/ closure strip	251.68
	Labor	500.00
	Total From Page One	2,140.75
	Total	$2,926.50

Address:

B.H. Bryan & Sons
Route 3, Box 152
Dillwyn, VA 23936

PH (804) 983-2869

DATE	CHARGES AND CREDITS	BALANCE
	BALANCE FORWARD	
	Backhoe & operator	
6-4-81	Footing for solar system	75.00

Spencer's Backhoe Service, Inc.

Thank You

PAY LAST AMOUNT IN THIS COLUMN

SS-462

SEAY MILLING & MACHINERY CO.

DILLWYN, VIRGINIA 23936

FEED MIXING & GRINDING

LIQUID NITROGEN
BULK FERTILIZER
SPREADER SERVICE

SEED, FEED, FERTILIZER, FARM SUPPLIES
McCULLOCH CHAIN SAWS AND HOME APPLIANCES
PHONE: 983-2011
TERMS: 30 DAYS NET - 1% SERVICE CHARGE ON ACCTS. 30 DAYS OLD FROM END OF MONTH

Order No. _____ Date 7/6 19 81

Name Bobby Bryan

Address

SOLD BY	CASH	C O D	CHARGE	ON ACCT	MDSE RETD	PAID OUT	☐ PICK-UP ☐ NON PICK-UP
			/				

QUAN	DESCRIPTION	PRICE	AMOUNT
~~Bot~~	Bolts		5 80
126	Washers		1 20
~~Bot~~	tags		2 38
2	Insulation	21.45	42 90
5	Nails	65	3 25
12	2"X8"X12'	7.50	90 00
13	2 1/4 Sand	.75	22 75
	Tax		6 73
	TOTAL		175 01

All claims and returned goods **MUST** be accompanied by this bill. T-599

025434

RECD BY Phil Lewis

☐

PHONE: 804/983-2011

SEAY MILLING & MACHINERY CO.

DILLWYN, VIRGINIA 23936

BUILDING MATERIALS • WATER SYSTEMS • HOME APPLIANCES

DATE July 22. 1981

NAME Bobby Bryan

ADDRESS

3 gal Black Paint	16.95	50	85
4 Silcone tubes	6.59	26	36
37 85. 4" Solder Blocks	.78	28	86
1 box 1/4 ARROW Staples			1.55
10 oz 16P Cement Coat Nails	.45	4	50
6 - 3/4 x 1/2 Bushing	.40	2	40
17 ft 3 ft Rat Wire		17	13
6 - P. 8 ft Corner Smart Rocks	1.30	7.	80
		135.	07
		5.	40
20%		140.	47

Terms: 30 Days Net — 1½ Service Charge On Accounts 30 Days Old From End of Month.

SOLD BY

DATE 6-17 1981

NAME Bobby Bryan

ADDRESS

PHONE

CITY

☐ CASH ☐ CHARGE ☐ MDSE. RET'D
☐ C.O.D. ☐ PAID OUT ☐ PD. ON ACCT.

QUAN.		DESCRIPTION	PRICE	AMOUNT
7½	1	yds. 2500 psi. conc	48 -	360 00
	2			14 40
	3			374 40
	4			
	5			
	6	@ FARM		
	7	3:00		
	8			
	9			
	10			
	11			
	12	Rocky Ford		
	13			
	14			
	15			
	16			

RECEIVED BY

TOTAL

No. 6103

Thank You

PHONE: 804/983-2011

SEAY MILLING & MACHINERY CO.

DILLWYN, VIRGINIA 23936

BUILDING MATERIALS • WATER SYSTEMS • HOME APPLIANCES

DATE 7-4-1981

NAME Bobby Bryant

ADDRESS

1	~~3/4 PVC Pipe~~		4 55
6	3/4 CPVC Coupling	23	1 38
2	3/4 CPVC Tees	53	1 06
2	3/4 CPVC Ells	35	70
4	Poly Male	395	15 80
12	4X4 -	500	60 00
1	~~Cold Water~~		14 65
1	Kinetico		460
			102 74

Chg

Terms: 30 Days Net — 1% Service Charge On Accounts 30 Days Old From End of Month.

PHONE: 804/983-2011

SEAY MILLING & MACHINERY CO.

DILLWYN, VIRGINIA 23936

BUILDING MATERIALS • WATER SYSTEMS • HOME APPLIANCES

DATE 5 June 17-1981

NAME Bobby Bryan

ADDRESS

1500 - 4X8X16 —
Solid - Block. +
16.
#1,140.00

Sale top of
In Empty

Rt. 15 South
Turn Right on 640.
Pass Anderson Ville ~~Road~~ STORE
Turn ~~Left~~ on 638 —
left.
go 2 to 3 miles on Left

Friday

Order Phone
by
Jun 17/81

Terms: 30 Days Net — 1% Service Charge On Accounts 30 Days Old From End of Month.

FARMVILLE MANUFACTURING CO., Inc.

FARMVILLE, VA.

PIECES	ARTICLES	RATE	AMOUNT
50	[illegible]	[illegible]	34 00
			1 36
			35 36

feed

3-10-23

Check no 1402

ORDERED BY _____ DATE 2/21/23

SOLD TO _____

ADDRESS _____

FARMVILLE MANUFACTURING CO., Inc.

FARMVILLE, VA.

PIECES	ARTICLES	RATE	AMOUNT
2	½ x 4 x 8 ext plywood	17.15	34 10
2	8" x 8" x 1" Stump Grass	4.20	8 40
			42 50
	Gasp		1 [illegible]
			44 [illegible]

ORDERED BY _____ DATE 4/20/20

SOLD TO _____

ADDRESS _____

FARMVILLE MANUFACTURING CO., Inc.

FARMVILLE, VA.

PIECES	ARTICLES	RATE	AMOUNT
10	pc. 2x8'x1" styro ifoam	4.20	42 00
50	2x2x8' #2 com.	96	48 00
3	4x8x3/8 sheet rock	3.84	11 52
1	4' sheet rock mold	.80	80
			102 32
			4 09
	Check # 1002		106 11

Paid

Z.D.

ORDERED BY

DATE 5/4/81

SOLD TO Cash

ADDRESS

JOB

SALESMAN

FARMVILLE MANUFACTURING CO., Inc.

FARMVILLE, VA.

PIECES	ARTICLES	RATE	AMOUNT
1	Dadblade 7 1/4 combo		5 99
5	2x8x1" Styrofoam	4.20	21 00
4	1"x2"x8' fir	.56	2 24
6	2x4x8 P.T.		14 87
6	2x6x8' #2 com.		15 60
			61 15

Paid

ORDERED BY

DATE 5/4/81

SOLD TO Cash

ADDRESS

JOB

SALESMAN Z.D.



Specializing in Commercial and Farm Buildings Since 1953

ROANOKE WOOD PRESERVERS, INC.

2944 ORANGE AVE. N.E., ROANOKE, VA. 24012
ROUTE 460E (Lynchburg Hgwy.)
DIAL (703) 343-9386

PRESSURE TREATED POLES, POSTS & LUMBER
PRESERVATIVES PENTA & CCA
REYNOLDS ALUMINUM BUILDING PRODUCTS
THREADED, HARDENED STEEL NAILS

Date 7-14 19 81

Name Bobby H. Bryan — Cust. Order No.

T/A — Job No.

Address Rt. 3 Box 152 — Shipped To

City Dillwyn, Va. 23936 — Via

SOLD BY	CIRCLE CASH CHECK	COURTESY CHG.	CHARGE	ON ACCOUNT	CREDIT	PAID OUT	TERMS
					X		Net 10th

QUANTITY	DESCRIPTION	PRICE	AMOUNT
	CREDIT		
1	8' clear skylight	—	(21 18)
1	closure strip	—	(82)
			(22 00)
	No restocking chg. BR		

No finance charge is made on accounts paid by the 10th of the month following month of purchase. Accounts not paid by the 10th of the month following month of purchase will on our billing date be charged 2% each month (24% annual rate). The minimum charge is $1.00 on balances under $50.00. 10% restocking charge on merchandise returned. No refunds or exchanges on special orders.

No FINANCE CHARGE is made on accounts paid by the 10th of the month following month of purchase. Accounts not paid by the 10th of the month following month of purchase will on our billing date be charged 1% each month which is 12% ANNUAL RATE. The minimum charge is 50¢ on balances under $50.00. —10% Restocking Charge on merchandise returned.—
NO Refunds or Exchanges on Special Orders.

4% STATE TAX		(88)
TOTAL		(22 88)

No. 12048

Received by

ALL CLAIMS AND GOODS MUST BE ACCOMPANIED BY THIS INVOICE.



Specializing in Commercial and Farm Buildings Since 1953

ROANOKE WOOD PRESERVERS, INC.

2944 ORANGE AVE. N.E., ROANOKE, VA. 24012
ROUTE 460E (Lynchburg Hgwy.)
DIAL (703) 343-9386

PRESSURE TREATED POLES, POSTS & LUMBER
PRESERVATIVES PENTA & CCA
REYNOLDS ALUMINUM BUILDING PRODUCTS
THREADED, HARDENED STEEL NAILS

Date 7/21 19 81

Name Bobby H. Bryant Cust. Order No.
T/A Route 3 Box 152 Job No.
Address Dillwyn, Va 23936 Shipped To Telephone # 983-2869
City Via

SOLD BY HBP	CIRCLE CASH CHECK	COURTESY CHG.	CHARGE X	ON ACCOUNT	CREDIT	PAID OUT	TERMS Net 10th

QUANTITY	DESCRIPTION	PRICE	AMOUNT
12	8' Clear Skylights	21 18	254 16
12	Closer strips	82	9 84
			264 00

No **FINANCE CHARGE** is made on accounts paid by the 10th of the month following month of purchase. Accounts not paid by the 10th of the month following month of purchase will on our billing date be charged 1% each month which is 12% **ANNUAL RATE.** The minimum charge is 50¢ on balances under $50.00. –10% Restocking Charge on merchandise returned.–
NO Refunds or Exchanges on Special Orders.

4% STATE TAX		10 56
TOTAL		274 56

No. 12001

Received by Danielle Craft

ALL CLAIMS AND GOODS **MUST** BE ACCOMPANIED BY THIS INVOICE.

APPENDIX D

Example of Media Information

Torrence Farm

Torrence Farm: innovative ideas are used in producing quality milk



THE TORRENCE FAMILY–[from left] Dennis, Zane and Pat.

The sun may not always shine on the Torrence Farm, but when it does it's put to good use.

A solar collection system was installed on the 265-acre dairy farm to help reduce monthly electricity costs. Though still in the test stage, the innovative technique seems to be doing just what it was designed to do--save money.

"After two years, we've found the solar system provides 30 percent of our energy requirement in the winter and 50 percent in the summer," siad Dennis Torrence, farm operator.

The Torrence Farm was one of 10 Virginia farms chosen to participate in a solar research project by Virginia Tech, in cooperation with the U. S. Department of Agriculture and the Department of Energy.

With Torrence picking up half the cost and the federal government supplying the other half, a demonstration solar system was erected on the farm milking parlor. It now heats water for washing udders and cleaning equipment in the Grade-A milking center.

"It wasn't by chance that this farm was selected as a demonstration site," said James A. Smith, Appomattox County Extension agent. "Dennis is a very progressive farmer who's interested in trying new things. He jumped at the chance to have his dairy used as an on-farm research site."

A former vocational agriculture teacher, 41-year-old Dennis has undoubtedly drawn upon his background and training in the success of the family farm. He graduated from Virginia Tech with a B.S. degree in agricultural education in 1963, then received a master's degree in the same field from the University of Maryland in 1968.

"I enjoyed teaching very much and when I was teaching, the farm was a good way to get my mind off the job. What was once a hobby, has now turned into a business," Dennis explained.

Dennis left teaching after 13 years to return to the family farm and enter into a partnership arrangement with his father, Elliott. "As Dad grew older and the business grew, it was just too much to teach full-time and farm too," he recalled. "Because of the cost involved, I could have never left teaching to go into dairying unles I joined a family operation."

So in 1978, a tradition was continued when Dennis, his wife, Pat, and son, Zane, moved to the farm, becoming the fourth generation of Torrences to farm the same land since 1898.

Just this year, Elliott retired from farming, leaving Dennis totally responsible for management of the 50-cow dairy. Since returning to the farm, Dennis started several new practices, resulting in a significant increase in milk production and profits.

"I invested a great deal of money in artificial breeding, using top bulls," he stated. "I also enrolled the herd in the Dairy Herd Improvement Association (DHIA) and put the entire farm operation on the Virginia Agri-Management Association (VAMA) record keeping system."

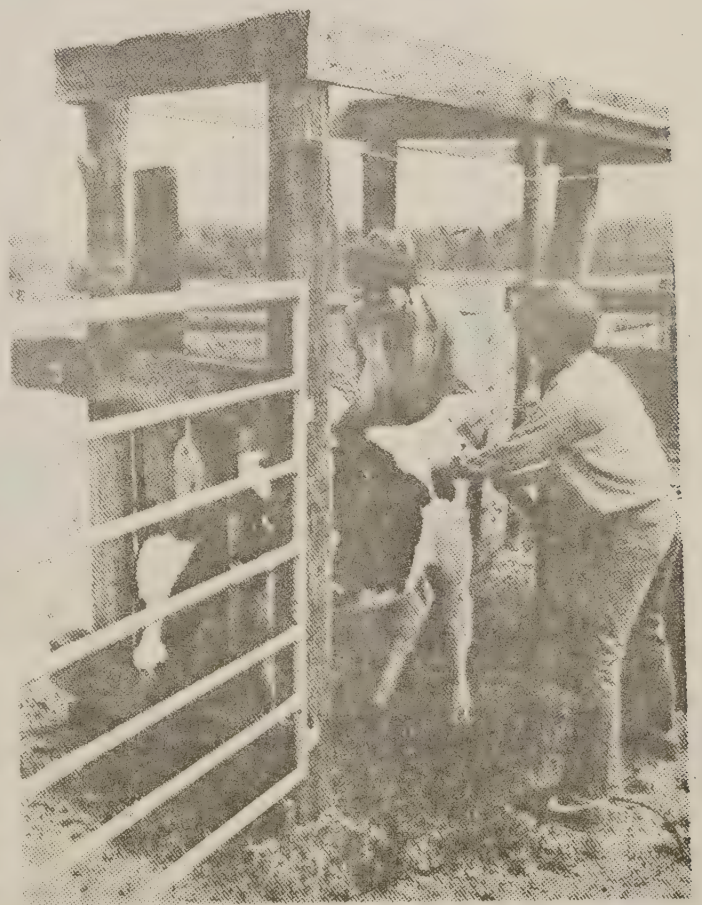
According to production figures, the management techniques have paid off. The herd is averaging 15,100 pounds of milk--a full 1,000 pounds over a year ago. DHIA projections on the herd two-year-olds call for a predicted 17,200-pound average indicating a bright future for the Torrence Farm.

Another indicator of a bright future is the recent "certified free" brucellosis rating received by the herd. With this rating, the Torrence cattle can move anywhere in the U. S. with few restrictions.

The Torrence success story has been accomplished without impressive buildings or expensive farm machinery. For example, Dennis still milks twice-a-day in a 20-stall stanchion barn built in 1948. "I examined building a modern parlor when I first came back on the farm," he explained, "but it would have cost $45,000 even back then."

Dennis has found the stanchion system to be satisfactory for a herd maximum of 60 cows. "Even in the winter, the barn stays a comfortable 55 degrees, the water never freezes,a nd you can hand-feed the cattle," he said. "It's an easier one-man way of milking and if a cow is not eating well, I can catch it right off. It's hard to do this

[Continued on page 17]



PAT AND ZANE ready a calf for a junior livestock show.

Torrence farm uses solar energy

[Continued from page 8]
when cattle are fed on an automatic feed bunk."

The easy-going farmer has found he must be constantly aware of keeping production costs below income. "Everything we buy has gone up," he noted. "The milk check is probably triple what it was four years ago, but the total profit isn't any more than it was then."

To help combat inflation, Dennis buys used equipment and keeps it in top-notch condition. The up-to-date dairyman explained the rationale behind this practice by citing a recent study. "It's been shown that those who make the most profit in dairying own the least amount of equipment," he said. "We have the bare minimum."

Nevertheless, the work gets done on the Torrence Farm. In addition to caring for the milk herd, Dennis uses the home farm and 128 rented acres to raise 50 acres of corn, 25 acres of alfalfa and 45 acres of oats and grass hay. Approximately 142 acres of pasture land and 136 forested acres round out this farming operation.

Although a dairy can be totally confining, the Torrence family finds time for recreation and relaxation thanks to Dennis' father, Elliott, and two hired hands who regularly perform milking chores every other weekend and when needed during the week.

Depending upon the season, Dennis, Pat, and 11-year-old Zane may be found snow skiing, traveling, fishing in the one-acre farm pond, or hunting with their beagles on the farm. A favorite pastime for Dennis and Pat is weekly square-dancing with the Appomattox Grand Squares. Zane enjoys showing cattle and has inspirations of studying veterinary medicine.

Because of the farm's close proximity to town, the Torrences host a number of half-day tours for school groups and handicapped persons each year.

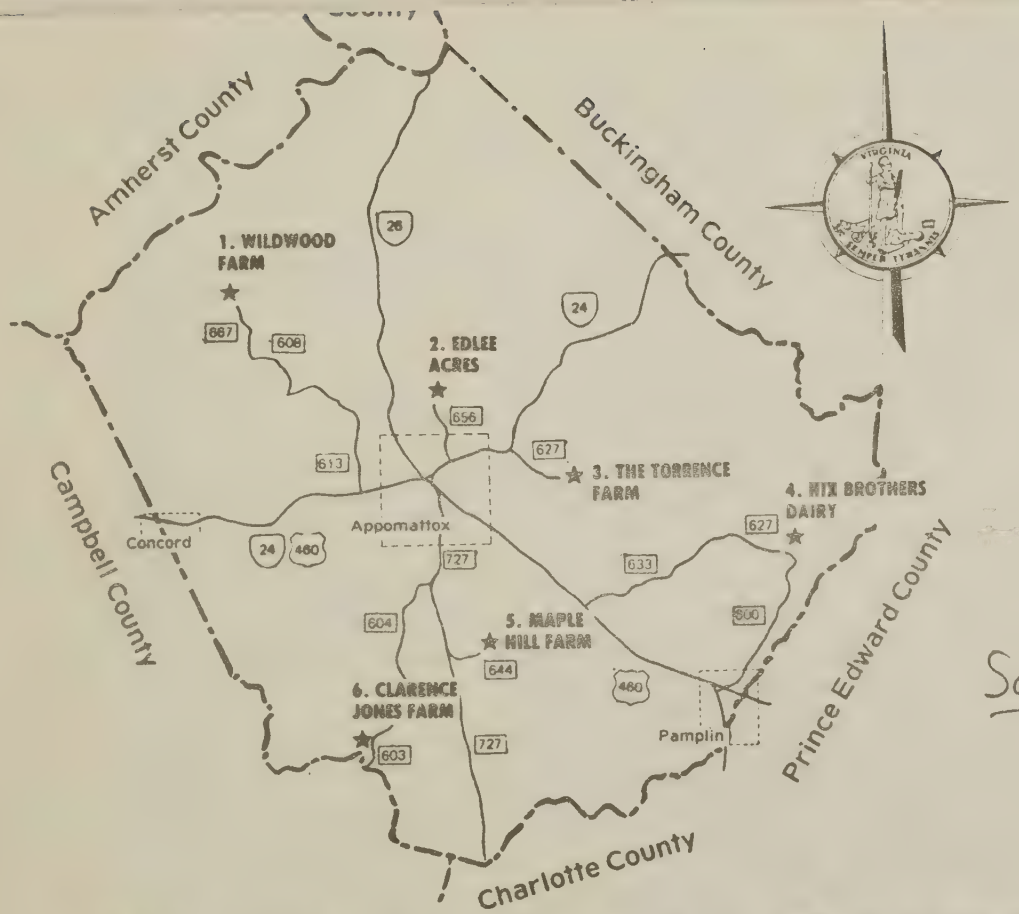
Pat, a primary school principal, said, "It's a real joy and learning experience for some of the small children and handicapped to actually visit a dairy and see a cow close up. We love opening our farm to them."

The farm is also used by high school Future Farmer groups as a "laboratory" whenever needed.

The Torrence Farm will be a laboratory for its biggest group yet when it plays host to the sixth annual Virginia Farm Management Tour, Saturday, July 17.

The farm will be one of the six highly-efficient, well-managed farm operations open to the public from 9:30 a.m. - 3:30 p.m.

The tour will be sponsored by the Virginia Cooperative Extension Service in cooperation with Appomattox County agricultural leaders.



Directions to Tour Farms

(From the Town of Appomattox)

1. WILDWOOD FARM - Drive west on U.S. 460 for 1.7 miles, turn right on Rt. 613 and drive 6.5 miles until it intersects Rt. 608, turn right and drive 0.6 mile, incline left on Rt. 667 and drive 1.1 mile to farm.

2. EDLEE ACRES - Drive northeast on State Rt. 24 for one-half mile, turn left on Rt. 656 and drive 1.4 mile to farm.

3. THE TORRENCE FARM - Drive 2.3 miles on State Rt. 24. Turn right on Rt. 627 and drive 1.9 mile to farm.

4. HIX BROTHERS DAIRY - Drive 4.6 miles east on U.S. 460, turn left on Rt. 633. Drive 4.2 miles until it intersects Rt. 627 and drive 2.5 miles to farm.

5. MAPLE HILL FARM - Drive south on State Rt. 727 four miles. Turn left on Rt. 644 drive .35 mile, incline left on Rt. 720 and drive .3 mile to farm.

6. CLARENCE JONES FARM - Drive south 1.9 miles on State Rt. 727. Turn right on Rt. 604, drive 6.2 miles to Rt. 603, turn left and drive .9 mile to farm.

Following are capsule comments about the farms featured on this year's tour:

1. WILDWOOD FARM

Jump on board the hay wagon for your tour of Wildwood Farm - a unique farm enterprise featuring forestry as its main activity. With 70 percent of Appomattox County in timber, brothers John and Phil Harrison found their steep, rolling land ideally suited for tree farming.

One of the larger farms in the county, this 908-acre operation is comprised of 300 acres open land and 100 acres cropland. The Harrison partners also manage a herd of 60 Angus beef cattle. Crops raised include 75 acres of hay, 12 acres wheat and 12 acres corn. Over 200 acres of loblolly pines are in various stages of growth.

On tour day, you can look forward to a firewood production demonstration, chainsaw care and operation demonstration, and tour of the Harrison's logging operation. High-tensile smooth wire farm fencing can also be seen on this farm.

2. EDLEE ACRES

This purebred Angus farm is owned and operated by Ed and Lee Ann Anderson and their son, Andy.

A 250-acre operation, it supports 50 top-flight females (each known by name to Andy). Good pastures, stockpiled fescue and hay provide the bulk of the feed. Usually 10 acres of corn are grown for silage and grain.

These outstanding Angus cows average 1,200 pounds and are enrolled in the Angus Herd Improvement Record Program. All females are synchronized and bred artifically by Ed. Purebred bulls are marketed throughout south central Virginia.

On tour day, see artificial insemination and estrous sychronization demonstrated. A round bale storage system will also be exhibited.

3. THE TORRENCE FARM

Interested in solar technology? Then be sure to visit this innovative farm. One of 10 Virginia farms chosen as part of a solar energy study, the Torrence Farm features a solar collection unit that is used to heat water for the Grade-A dairy.

A father-son partnership until a year ago, the farm is now operated by Dennis Torrence, a former vo-ag teacher. Since returning to full-time farming, Dennis has greatly increased milk production on his 50-plus Holstein herd. Milking is performed in a 20-unit stanchion barn.

Around 400 acres of owned and rented land are used to raise 50 acres of corn, 45 acres of hay and 70 acres alfalfa. Approximately 142 acres of pastureland and 136 forested acres round out this farming operation.

On tour day, don't miss the computer displays set up by Virginia Tech Extension specialists. See the latest in computerized ration formulation and how a personal computer can be applied to farm problems.

4. HIX BROTHERS DAIRY

The county's highest producing Grade-A dairy will be open for visitors on this year's tour. Owned and operated by two brothers, John and William Hix, the farm features 120 "black-and-whites" that average 17,000 pounds of milk.

The herd has been on DHIA test for 12 years and milking is done in a double-six herringbone parlor built in 1977. The conservation-minded Hix brothers recently installed a unique watering system for their cattle, utilizing some underground drainage.

The production of animal feed is a high priority for this 1,100-acre operation. Nearly 70 acres of alfalfa, 80 acres of small grain, 110 acres of corn and 50 acres of orchardgrass-clover hay are grown and harvested.

Visit this century-old farm on July 17. You'll see a farm safety demonstration by Virginia Tech Extension specialists and Appomattox Rescue Squad volunteers. Learn to help farm accident victims.

5. MAPLE HILL FARM

Dark fire-cured tobacco and beef cattle point up the diversification of this typical central Virginia farm.

Owned and operated by Carter and Louise Martin, Maple Hill Farm is comprised of 280 acres. The Martins have a four-acre allotment of dark tobacco and Carter is a recognized authority on its production and curing. Twelve acres of corn, 25 acres of hay and 12 acres of wheat form the crop rotational system.

A herd of 50 Hereford beef cows allow some flexibility in the management scheme. This outstanding herd has been developed over many years by Carter. Use of performance tested bulls contribute to the above-average growth rate of the cattle. Carter regularly markets 600 pound steers (the state average is 425 pounds).

Visitors to Maple Hill will see tobacco grading demonstrations and the latest in farm sprayer technology.

6. CLARENCE JONES FARM

Tobacco is "king" on this highly-specialized farm owned by Clarence and Dale Jones. The husband-wife team operate the farm as a partnership, working side-by-side from planting through harvest.

Approximately 60 acres of tobacco and 100 acres of wheat are raised on the 360-acre tract. Three types of the "golden leaf" are grown - 48 acres acres of flue-cured (used primarily for cigarettes), 10 acres of dark fire-cured (used for snuff and cigars), and two and one-half acres of burley (used for cigarettes and chewing).

Five bulk barns, each costing about $12,000, yield 3,000 pounds of cured leaf each week during harvest season making this farm the largest tobacco farm in Appomattox county.

Several pieces of tobacco equipment will be displayed on tour day

PURPOSE

ABOUT APPOMATTOX COUNTY

SIXTH ANNUAL

3. **THE TORRENCE FARM** - Drive 2.3 miles on State Rt. 24. Turn right on Rt. 627 and drive 1.9 mile to farm.

1.9 miles on State Rt. 727. Turn right on Rt. 604, drive 6.2 miles to Rt. 603, turn left and drive .9 mile to farm.

Five bulk barns, each costing about $12,000, yield 3,000 pounds of cured leaf each week during harvest season making this farm the largest tobacco farm in Appomattox county.
Several pieces of tobacco equipment will be displayed on tour day

PURPOSE

Virginia's sixth annual Farm Management Tour is designed to help farmers do a better job. By exchanging information with other successful farm-based people, there is an opportunity for education, motivation and challenge. Farming is Virginia's number-one industry. What is learned on this year's tour can make it even better.

TOUR SCHEDULE

Tours and management discussions will be conducted continuously throughout the day at each farm from 9:30 a.m. until 3:30 p.m. The tour is self-directed and self-scheduled.

LUNCH MENU

Lunch will be served at two of the farm tour stops from 11 a.m. until 2 p.m.:

Wildwood Farm -- Stop No. 1

Hix Brothers Dairy -- Stop No. 4

Cost of each catered meal will be $3 and will include both a hamburger and a hot dog, baked beans, potato salad, cole slaw and a drink.

INFORMATION

Before the tour, requests for information should be directed to the Appomattox County Extension Office in Appomattox. Telephone (804) 352-8244. Groups are encouraged to travel by bus and should contact the Extension Office for a tour guide at least two weeks before the tour.

Written requests for information should also be directed to the county Extension Office, Box 488, Appomattox, VA 24522.

Tour Routes will be well-marked with orange and black signs placed at strategic locations throughout the county. Information booths will be manned throughout the day at Big Horn Market in Concord (intersection of U.S. 460 and State Route 24, west of town of Appomattox); at Farmers National Bank (Triangle Plaza, in town of Appomattox); and at Pamplin Exxon near Pamplin (U.S. 460, east of town of Appomattox).

On tour day, questions should be directed to tour aides who will be wearing specially designed blue and gray caps imprinted with the Farm Management Tour

ABOUT APPOMATTOX COUNTY

Nestled in the gently rolling hills of Virginia's Piedmont region, Appomattox County offers a pleasant blend of past and present to those participating in the state's sixth annual Farm Management Tour.

The county was formed in 1845. Sixteen years later, our nation was thrust into the Civil War, a conflict that was to end at the obscure Virginia village of Appomattox Court House, a hamlet typical of many across the South. It was here that General Robert E. Lee surrendered his Army of Northern Virginia to General Ulysses S. Grant.

The surrender was signed ceremoniously in the McLean House, a genteel southern home purchased by Wilbur McLean in 1863. McLean and his family had left their plantation near Manassas, the scene of the Civil War's first major clash, and moved to the hill country where, they hoped, "the sounds of battle would never reach."

Fate decreed, however, that the war which began on McLean's Northern Virginia plantation would end in his living room.

That living room, as well as the entire McLean House and the village of Old Appomattox Court House, are preserved today in the Appomattox Court House National Historical Park on Route 24, northeast of the town of Appomattox.

Appomattox, known as the place "Where Our Nation Reunited," is today a bustling rural community located in the geographical center of the Old Dominion.

The farming operations featured on this year's management tour are of the type which form the backbone of rural America's economy.

These farms are small to average in size, relatively speaking, and the owners are directly involved in the day-to-day operations of the farms. From milking cows to maintaining financial records, these farmers are working men who depend on themselves and their families for the success of their businesses.

The host families of this year's Farm Management Tour, and the agricultural community in general welcome you to Appomattox County on July 17.

We hope you will enjoy the tours and take advantage of the slice of American history preserved in Appomattox County.

The 1982 Farm Management Tour is sponsored by the Virginia Cooperative Extension service in cooperation with Appomattox County

SIXTH ANNUAL VIRGINIA FARM MANAGEMENT TOUR

APPOMATTOX COUNTY
JULY 17, 1982



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1022370682